Olmsted

A

COMPENDIUM

OF

NATURAL PHILOSOPHY:

ADAPTED TO THE USE OF

THE GENERAL READER,

AND OF

SCHOOLS AND ACADEMIES.

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PREFACE.

It is the object of this work, to present to the general reader, and to the more advanced pupils in our Schools and Academies, the most important PRACTICAL RESULTS of Natural Philosophy, (without the demonstrations,) in as condensed and intelligible a form as possible, and to exemplify them by a great variety of applications to the phenomena both of nature and art.

Within a few years past, great efforts have been made, especially in England, to divest science, as far as possible, of every thing technical, and to render its most important practical principles intelligible to every well informed reader. The profoundest truths are often capable of being expressed in terms that are plain and easily understood, although the reasonings by which those truths were investigated, and the proofs by which they are established, may involve refined and intricate mathematical processes. Leaving, therefore, the *demonstrations* to such as are professionally devoted to science, it has been proposed to take the *results* only for the use of the general reader, and to show their applications to the useful arts, and to the explanation of natural phenomena.

By this means, not only will scientific knowldege be far more widely diffused, but the useful discoveries of science may thus be rendered available to artists, and others, who will reduce them to practice. It was with this view that the scientific treatises in the Library of Useful Knowledge, were prepared and published, at the suggestion, and under the auspices, of the late enlightened Lord Chancellor of England. Some of those treatises are well adapted to the purpose in view; others are ill-suited to the wants of the general reader; and they were evidently composed by men little conversant with the tastes and attainments of those for whom they were professedly written. Individuals, also, of profound acquirements and of high standing in the scientific world, have embarked in the same enterprise. Among the most successful of these, is Dr. Lardner of the London University, whose writings on the several branches of Mechanics, and Lectures on the Steam Engine, are among the best attempts at reducing scientific principles to the popular standard. Dr. Bigelow's "Elements of Technology," is a highly useful and respectable work of the same class; and a few others might be mentioned which are deserving of a similar character. Many of the writers, however, who have published scientific works designed for general reading, or for schools, make their works easy of comprehension, merely because they introduce into them nothing but the simplest and most superficial parts of the subjects of which they treat, and consequently give to the learner nothing but a *smattering* of science,—too little either to enlighten his mind, or to qualify him to appropriate the resources of science to his practical benefit.

During the years 1831 and 1832, the writer published a work on Natural Philosophy, in two volumes 8vo. designed as a text book for students in college.* He has been frequently solicited to prepare a volume like the present, suited to the purposes of the general reader, and adapted to a portion of the students in our High Schools and Academies, who have not made the attainments in mathematics requisite for perusing the larger work. Such a work is the volume now offered to the public. It contains the most important principles of Natural Philosophy, with ex-

* *A second edition of that work, was published in 1835.*

tensive practical applications, and requires no farther attainments in mathematics than a knowledge of common arithmetic.

The writer, while he has studied plainness and perspicuity, has not deemed it either necessary or expedient, to expound the doctrines of Philosophy in a juvenile, not to say *puerile*, style, with the view of making it more intelligible or more attractive to young minds. Such a style he believes to be no more intelligible than the ordinary style of philosophical writing; and he would desire the youngest student of philosophy to receive the impression, that the study owes its attractions to its own inherent dignity and utility,—to the elevation of its truths, and to their great practical importance.

The elevated course of study adopted in some of our schools, both male and female, requires a corresponding improvement in the books prepared for their use. In many of these seminaries, it is hoped that there will be pupils sufficiently advanced in mathematics, to read the more elaborate works on Natural Philosophy; while a still larger proportion perhaps, will find the present treatise sufficiently extensive for their use.

The numerous Voluntary Associations formed in various parts of our country, for philosophical inquiry, will, it is believed, find the present work well adapted to promote their objects; especially, on account of its numerous practical applications of the principles of science to the arts, and the purposes of life. Professional gentleman, also, and others of liberal education, will find this small treatise favorable for reviewing subjects, which, in the course of their collegiate education, they may have studied in a more difficult form. They may, moreover, meet with some things here, which the progress of the science has brought to light, since the time when they were students in Philosophy.

With respect to the *sources* from which the materials of this volume have been drawn, they are, for the most part, the same as those of the larger work, where they are indicated in the margin. This work being professedly a compilation, illustrations have been adopted freely from such practical works as those of Lardner, Brewster, and Herschel.

Yale College, December, 1836.

ANALYSIS.

COMPENDIUM

OF

NATURAL PHILOSOPHY.

PART I.—MECHANICS.

CHAPTER I.

PRELIMINARY PRINCIPLES.

1. NATURAL PHILOSOPHY *is the science which treats of the Laws of the material world.*

The term *Law*, as here used, signifies *the mode in which the powers of nature act.* Laws aim at determining things with numerical precision, or of assigning the exact proportions in which effects take place. Thus, it is a property of light to be reflected from smooth surfaces; but it is a *law* of light that the incident and the reflected rays make *equal* angles with the surface. It is a property of all bodies, when let fall in the atmosphere, to descend towards the centre of the earth; but the *laws of falling bodies* determine, precisely, *how much* farther a body falls in two seconds than in one. Laws are *general truths*, comprehending a great number of subordinate truths. Thus, it is a fact that heat enlarges the bulk of a cannon ball; but this single fact would not constitute a law of heat. The law is, that heat expands *all* bodies.

Natural Philosophy is divided into Mechanics, Electricity, Magnetism, and Optics.

2. MECHANICS *is that branch of Natural Philosophy, which treats of the equilibrium and motion of bodies.** This definition

Define Natural Philosophy. What does the term *Law* signify? Give an example of a *property* of light, as distinguished from a *law* of light. Same distinction in regard to falling bodies. Give an example to show that laws are *general truths.* How is Natural Philosophy divided? Define Mechanics.

*That is, of bodies in a state of rest or motion, and of the forces that keep them in these states respectively.

refers to Mechanics as a science; the principles of the science applied to the purposes of life, as in the construction of machinery, constitute *Practical Mechanics*. The arts of life are partly mechanical and partly chemical. Mechanical effects involve only changes of *place* and of *figure*; but chemical effects involve a change of *nature*. Thus the act of mixing the ingredients of bread is mechanical, because it merely brings things together, producing only change of place; the unseen union of the particles of flour, yeast, and water, forming dough, a new substance different from any of these, is a chemical change, because it alters the *nature* of the substances; making the loaves is mechanical, involving only a change of form; and finally the baking is a chemical process, because it still farther alters the nature of the body.

Body, is any collection of matter existing in a separate form. The word *particle* is much used in writings on physical subjects. In Natural Philosophy, we mean by particles, the *smallest parts* into which a body may be supposed to be divided by mechanical means, without any reference to the different elements of which such particles may be composed. Inquiries of the latter kind belong to Chemistry; and, in general, we recognize no distinctions among the different kinds of matter which constitute various bodies, and classes of bodies, (except what relates to the states of solid and fluid,) leaving to Chemistry all inquiries respecting the composition of bodies, and the changes of nature which bodies undergo by their action on each other.

3. *Force* is any cause which moves or tends to move a body, or which changes or tends to change its motion. Thus the elastic power of steam in propelling a boat, the action of the wind upon a sail, of a weight upon a clock, and of an animal in dragging a carriage, are severally examples of forces in actual operation.

That part of Mechanics which relates to the action of forces producing equilibrium or rest in bodies, is called *Statics*; that which relates to the action of forces producing motion, is called *Dynamics*.

4. The laws of equilibrium and motion undergo certain modifications in consequence of the peculiar properties of

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Define *Practical Mechanics*. What changes in bodies are Mechanical and what are Chemical? Give an example. Define *body*—also, *particle*. What science treats of the different kinds of matter? Define *force*. *Examples*. Define *Statics*. Also, *Dynamics*.

fluids. Hence, that branch of Mechanics which treats of the equilibrium and motion of fluids in the form of water, is called *Hydrostatics;* and that which treats of the equilibrium and motion of fluids in the form of air, is called *Pneumatics.*

5. The two *essential* properties of matter, both of which are inseparable from it, are *extension* and *impenetrability.* Extension, in the three dimensions of length, breadth, and thickness, belongs to matter under all circumstances; and impenetrability, or *the property of excluding all other matter from the space which it occupies,* appertains alike to the largest body and to the smallest particle, and to bodies under every form, solid, fluid, and aëriform. In Geometry, we conceive figures to possess extension only without solidity; or to occupy space without excluding other bodies from it; but in Mechanics, we take objects as they occur in nature, viz. not only extended but impenetrable. Thus, in the demonstrations of Geometry, a sphere is represented as existing in the midst of a cylinder, both bodies being supposed, for the sake of comparing their relations with one another, to occupy the same space; but when we seem to penetrate matter, as in driving a nail into wood, the nail does not *penetrate* the wood, it *displaces* it; and the same is the case when a body is introduced into water or air.

6. Besides the two essential properties of matter, extension and impenetrability, there are various other properties which are not considered as essential to the very existence of matter, since bodies might be conceived to exist without them, although some of them are in fact always present. Of these, two are intimately connected with the phenomena and laws of motion: they are *Gravity* and *Inertia.*

GRAVITY *is that property, by which all terrestrial bodies tend towards the center of the earth.* It is in this sense that gravity is understood as a force in Mechanics. But in order to give the learner correct views of this important subject, we subjoin a few other particulars respecting it.

7. *Gravity is a property of matter, universally; and the force of gravity in any body, is proportioned to its* QUANTITY OF MATTER.

Define *Hydrostatics* and *Pneumatics.* What are the two essential properties of matter? In what different lights are bodies considered in Geometry and in Mechanics? Examples. Define Gravity.

Gravity extends to all bodies in the universe, from the smallest to the greatest; but the consideration of the subject, in this extent, belongs to Astronomy. We at present contemplate gravity only as it affects *terrestrial* bodies. By it all bodies are drawn towards the center of the earth, not because there is any peculiar property or power in the center, but because, the earth being a sphere, the *aggregate* effect of the attractions exerted by all its parts upon any body exterior to it, is such as to direct the body towards the center. This property discovers itself, not only in the motion of falling bodies, but in the *pressure* exerted by one portion of matter upon another which sustains it; and bodies descending freely under its influence, whatever be their figure, dimensions, or texture, are all equally accelerated, in a direction perpendicular to the horizon. The apparent inequality of the action of gravity upon different species of matter near the surface of the earth, arises entirely from the resistance which they meet with in their passage through the air. When this resistance is removed, (as it may be done by means of an instrument called the Air Pump, to be described hereafter,) no such inequality is perceived; but a guinea, a feather, and the smallest particle of matter, if let fall together, from the same height, will reach the plane exactly at the same instant.

8. *The attraction of gravitation is* RECIPROCAL, *or every body attracts every other precisely as much as it is attracted by it.*

The earth has about seventy times as much matter as the moon, yet the moon attracts the earth just as much as the earth does the moon. Nor is this doctrine inconsistent with that asserted in Art. 7, namely, that the force of gravity in a body is proportioned to its quantity of matter; for, although the earth by containing seventy times as much matter as the moon, exerts a force seventy times as great as it would do were it of the same weight with the moon, yet it also, on the same account, is capable of receiving from the moon seventy times as much; and what the earth gains by its greater power of *imparting*, the moon gains by the earth's greater power of *receiving*. Suppose the earth divided into seventy parts, each equal to the moon. Now

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Is Gravity a property of all matter? To what is it proportioned? Why is this force directed towards the *center* of the earth? How is its direction with respect to the horizon? Are all bodies equally accelerated by it? Why do light and heavy bodies fall with unequal velocities? *State the* law of the *reciprocal* attraction of gravitation. Example in *the mutual action* of the earth and the moon.

each of these parts will act and be acted on with the same force as the moon. Hence, the attraction of the moon being unity, that of the earth for the moon is seventy, and that of the moon for the earth is the same, being equal to what it would exert upon seventy bodies each equal to itself.

The *weight* of a body is the force it exerts in consequence of its gravity, and is measured by its mechanical effects, such as bending a spring, or turning a balance; or it is measured by the force which it takes to hold a body back, so as to keep it from falling. The force thus exerted by a given mass of matter, (as a cubic foot of water,) being taken as the standard, called 1000, and accurately counterpoised in a balance, by some substance easily susceptible of division, as a mass of lead, for example, multiples or aliquot parts of this standard weight afford the means of estimating the weights of all other bodies. Hence, *weights are nothing more than measures of the force of gravity in different bodies;* but since the force of gravity is proportioned to the quantity of matter, (Art. 7.) weights are also measures of the comparative quantities of matter in different bodies.

9. *Gravity at different distances from the earth, varies inversely as the* SQUARE OF THE DISTANCE *from its center.*

The meaning of this proposition is, first, that as the distance from the center of the earth increases, the force of gravity diminishes; and secondly, that the degree of diminution, is not simply proportional to the increase of distance, so as to be one half at double the distance, and one third at three times the distance, but it is proportioned to the *square* of the distance, so that at twice the distance it is only one fourth as great, at three times the distance, only one ninth, and at a hundred times the distance, only one ten thousandth part as great. The weight of a body, therefore, will vary at different heights above the earth's surface. Thus at the height of 4000 miles, (which is about twice as far from the center of the earth as bodies on the surface are,) a body would weigh only one fourth as much as at the earth; and the moon, being about 60 times as far from the center of the

Define *weight.* How is it measured? How is it related to the quantity of matter? State the law of gravity at different distances. How much less is a body attracted when *twice* the distance of another body from the center? How much when three times the distance? How will the weight of a body be affected by being raised above the general level of the earth? How much would a weight lose at the height of 4,000 miles—*also, at the height of* the moon?

earth, as the distance from that center to the surface, the attraction of the earth upon the moon is the square of sixty, that is, 3600 times less than upon bodies near the earth; and, consequently, very heavy bodies would become very light, if carried to such a distance from the earth. For example, a cart load weighing a ton, would if lifted to such a height as the moon, weigh less than ten ounces; and a man of the largest size, whose weight was four hundred pounds, would under such circumstances, weigh less than two ounces. But the heights at which experiments are commonly made upon the weights of bodies, are so small in comparison with the radius of the earth, that the loss of weight, at different elevations, is hardly perceptible. At the height of *half a mile*, the loss could not amount to more than $\frac{1}{4000}$th part of the weight at the general level of the earth, so that a ton of lead would lose only about nine ounces, by being weighed on the top of a mountain half a mile high; but at such an elevation as the top of Chimborazo, (which is nearly four miles high,) the diminution of weight would be material, being, in a ton, about four pounds and nine ounces. For, since the weights are inversely as the square of the distances from the center of the earth,

$$\overline{4004}^2 : \overline{4000}^2 :: 2240\text{lbs.} : 2235\text{lbs. } 7\text{ oz.}$$

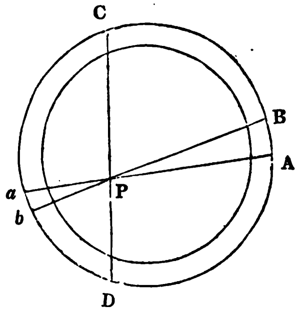
That is, a ton of lead would weigh on the top of Chimborazo 2235 pounds and 7 ounces, and of course would lose 4 pounds and 9 ounces. Hence, standard weights are adjusted at the level of the sea.

10. *A body situated within a hollow sphere, would remain at rest in any part of the void.*

Were the earth a hollow shell, with a crust more or less thick, a ball introduced into any part of the empty space, would remain perfectly at rest, and not fall either way. Were the ball placed in the center, it is easy to see that this would be the case, since it would be attracted equally on all sides; but were it placed out of the center, and much nearer to one side than to the other, it would still remain at rest; for while the nearer portions of the crust would attract it more than the remoter portions, there would be so much more matter on the side of the latter, as to counterbalance the advantage which the former derived from its greater proximity.

How much would a ton weigh at the moon? What is the loss of weight half a mile high? State the law of a body situated in a *hollow sphere*. *Suppose the* body placed at the center—why would it be at rest when out of the center?

Fig. 1.



Thus in Fig. 1. if the space between the two concentric circles represents the supposed crust of the earth, and a body were situated in the void at P, it would be attracted as much more on the left of the line CD, on account of its being nearer to the matter on that side, as it would be on the right of the same line in consequence of the greater quantity of matter in that direction. It would therefore remain at rest between equal forces. If therefore, a man were let down by a rope through a hole which penetrated the crust, the force required to support him, (in other words, his *weight*,) would grow continually less and less until he reached the void, when it would be nothing.

11. *The force of gravity below the earth's surface is, at different distances from the center, directly proportioned to those distances.*

Since the force of gravity, acting on bodies exterior to the earth, increases rapidly as they approach the earth, some have erroneously supposed that if a body could be let down through a pit towards the center of the earth, its weight would be greatly augmented; but, so far is this from the fact, that were a body thus to descend into the earth, its weight would be continually diminished until it reached the center where it would be nothing. This will be plain, if it be considered, that weight is nothing more than the measure of the force of attraction (Art. 8.); that a body when placed at the center of the earth would be attracted equally in all directions; and that, at any point above the center, there would be matter exterior to it which, by its attraction, would draw it back, and counteract its tendency to descend, and of course detract so much from its weight.

12. INERTIA *is a property of matter by which it resists any change of state, whether of rest or motion.*

Demonstrate the proposition by the figure. State the law of gravity *within* the earth, at different distances from the center. Explain the reason of this law. Define *Inertia.*

The inertia of a body at rest, is the resistance to be overcome to bring it to a given velocity; or, in common language, "to start it;" and the inertia of a body in motion, is the resistance it makes to being stopped, after the moving force is withdrawn. Thus the inertia of a steam boat, while getting under weigh, requires a great expenditure of force to bring the boat to its final velocity; but its inertia carries it still forward after the engine is stopped. Since every particle is endued with this property, *the inertia of a body is proportional to its quantity of matter, and of course to its weight.*

13. Were a hole bored through the earth, and a cannon ball let fall into it, from the surface, the ball would be accelerated until it reached the center, although at a rate constantly diminishing. After it passed the center, it would be constantly retarded; but in consequence of its inertia, it would rise to the opposite surface, where it would lose all the motion acquired in falling, and being again attracted towards the center, would continue to vibrate through the earth forever.

CHAPTER II.

OF MOTION AND FORCE.

14. Motion and rest are accidental states of bodies, nor is a body naturally prone to one state, more than to the other. If it is found at rest, it is because it is kept at rest by opposite and equal forces; and if it is found in motion, it is because it has been put in motion by some force extrinsic to itself. The resistances to motion which exist near the surface of the earth, particularly gravity, create a seeming tendency to a state of rest; but in reality rest is no more the natural state of bodies than motion is.

15. Motion is distinguished into absolute and relative.

Absolute motion, is a change of place with respect to any fixed point: *relative motion*, is a change of place in bodies with respect to each other. When a man walks towards the

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What is the inertia of a body at rest? What is the inertia of a body in motion? Example in a steam boat. How is the inertia related to the quantity of matter and the weight? State the case of a ball falling through the earth.

Are motion and rest natural or accidental states of bodies? Why is *any body at rest?* Why is any body in motion? Define *absolute motion—define relative motion?*

stern of a ship, he is in motion with respect to the ship, but may be at rest with respect to the shore. When a balloon, carried along by the wind, attains the same velocity as the wind, it is relatively at rest, and appears to the aëronaut to be in a perfect calm, though it may be actually moving sixty miles an hour. Since the earth, in its annual revolution round the sun, is moving eastward at the rate of 100,000 feet per second, were a cannon ball, at a certain time of day, fired eastward at the rate of 2000 feet per second, the only effect would be to add 2000 feet to the velocity which the ball had before in common with the earth; and were it fired westward, the effect would be merely to stop 2000 out of 100,000 parts of its previous motion, while the cannon would proceed onwards leaving it behind. Did not the atmosphere partake of the diurnal motion of the earth, but were it to remain at rest with respect to this motion, the progress of any place to the eastward, would cause a relative motion of the air, or a wind westward, which would blow with a violence far surpassing that of the most terrible hurricanes.

16. *Apparent motion*, as distinguished from relative, is that in which the moving body is quiescent, and the seeming motion is owing to a real motion in the spectator. Thus the backward motion of the trees to one riding rapidly, the receding of the shore to one who is sailing from it with a fair wind, and the diurnal motion of the heavenly bodies from east to west, in consequence of the revolution of the spectator in an opposite direction: these are severally examples of apparent motion. It is often a very difficult problem to deduce the real from the apparent motion. We can sometimes decide that a given motion is *real*, because we observe a *cause* in operation which is competent to produce it. The impulse of the wind, or the direction of the current, will satisfactorily account for a ship's receding from a given object, while no cause appears why the object should recede from the ship. The revolution of the earth on its axis, is competent to explain the apparent revolution of the heavens, while we can find no cause for their actual revolution. The *effects* also of a give nmotion, enable us to decide whether it is real or apparent. Thus, a constant tendency to move in a straight line, is characteristic of real motion.

Examples of motion on board of ship, in a balloon, in the revolution of the earth. Define *apparent motion*. Examples in the backward motion of trees, of the shore, and of the diurnal motion of the heavenly bodies. How can we decide between apparent and real motion?

17. There are three particulars which are concerned in all the phenomena of motion; namely, the *space* over which a body moves, the *time* of its motion, and the *velocity* with which it moves. If the motion of a body be such, that *it describes equal spaces in equal successive parts of time;* then it is said to move with *uniform* velocity. Thus, when a ball rolls just as far the second second as the first, and the third as the second, its velocity is uniform. When the spaces described in equal successive parts of time continually increase, it is said to move with an *accelerated* velocity; and with a *retarded* velocity, when those spaces continually decrease. If its motion be so regulated, that it receives equal increments of velocity in equal successive parts of time, then it is said to be *uniformly accelerated;* and *uniformly retarded*, if the body suffers equal decrements of velocity in those equal portions of time.

The leading principles of uniform Motion, are comprehended in the three following propositions, which are to be treasured up in the memory.

18. I. *The* SPACE *equals the product of the time multiplied into the velocity.**—Thus, a body moving at the rate of 40 feet per second for 10 seconds, would evidently pass over a space equal to ten times 40, that is 400 feet.

19. II. *The* TIME *equals the space divided by the velocity.*—If, for example, a body has passed over 400 feet at the rate of 10 feet per second, then $10 : 1'' :: 400 : \frac{400}{10} = 40$ seconds.

20. III. *The* VELOCITY *equals the space divided by the time.* Thus, if a body has passed over 400 feet in 10 seconds, it must have proceeded at the rate of 40 feet per second: for,

$$10'' : 400 :: 1'' : \tfrac{400}{10} = 40.$$

Hence, in uniform motions, if any two of the three particulars, space, time and velocity, be given, the other may be found. This may be illustrated by a few examples.

When is a body said to move *uniformly.* Example in a ball rolling. When does a body move with *accelerated* velocity? When with a *retarded* velocity? Three propositions on uniform motion, viz:—What does the *space* equal? The time? The velocity? Give examples of each. When the space and time are given, how may we find the *velocity?* When the space and velocity are given, how may we find the *time?* When the time and velocity are given, how may we find the *space?*

*The young learner is apt to be puzzled with such abstract expressions as time multiplied into velocity; but it may be observed, that by velocity is meant nothing more than *the space passed over* in one second; which may evidently be so multiplied as to equal another space.

21. *Questions on Uniform Motions.*

1. If a body moves uniformly 9 seconds with a velocity of 17 feet per second, through what *space* will it pass? Ans. 153 feet.

2. The space described by a body is 540 feet; the velocity with which it moves is 6 feet per second; what will be the *time* of its motion? Ans. 90 seconds.

3. A body describes 560 feet in 9 seconds: what is its *velocity?* Ans. $62\frac{2}{9}$ feet per second.

4. A bird of passage was observed to fly with a uniform velocity of 15 feet per second: over what *Space* would she pass in 24 hours? Ans. $245\frac{5}{11}$ miles.

5. A lame man set out to travel round the world. He could walk but one mile an hour for eight hours out of the twenty four. Provided he could go forward, without impediment, on the circumference of a great circle of the globe, which is 25,000 miles round, what *Time* would he require to complete the journey? Ans. 8 years and 205 days.

6. A wind blows uniformly from the equator to the pole (say 6,000 miles) in ten days: what is its *Velocity* per hour? Ans. 25 miles.

22. *Momentum and Force.*

The MOMENTUM *of a body is its quantity of motion, and is proportioned to the product of its quantity of matter and velocity.*

If two balls, equal in weight, be rolled with the same velocity, it is evident that they will together have twice as much motion as either of them alone. Also, ten balls, in like circumstances, would have ten times as much motion as one ball. Nor would it make any difference, as to the amount of motion, whether they moved separately, or were united in one mass. With a given velocity, therefore, the momentum is proportioned to the quantity of matter. But the same balls, moving with twice or thrice as great velocity as before, would have twice or thrice as much motion: that is, the whole amount of motion, or the momentum, is found by multiplying the quantity of matter by the velocity. Thus a single ball may have as much momentum as one hundred similar balls, if it moves a hundred times as fast as they do; or, in general, a small mass of matter may have the same momentum with a large mass, if its velocity be as much greater as its weight is less.

Define *Momentum.* Example in balls rolled, first, with the same velocity, and *afterward, with different* velocities. How may a small mass *have the same momentum* as a large mass?

23. FORCE *is any cause which moves or tends to move a body, or which changes or tends to change its motion.* (See Art. 3.)

The measure of a force, is the change of motion which it produces; and the momentum of a body is determined by the force required to stop it. Momentum is estimated in pounds weight, a weight just sufficient to balance it being supposed to act against it by means of a cord passing over a pulley. Thus a cannon ball may be said to move with a momentum of 1,000 pounds, because, were a scale loaded with this weight and attached to one end of a cord, while the other end was attached to the ball, (the cord passing over a pulley,) the ball and the weight would exactly balance one another, and the ball would be said to move with a momentum of 1000 pounds. The weight, moreover, would be a *force* acting against the ball, *tending to move* it in the opposite direction.

24. *Questions on Momentum.*

1. A weighs 50 pounds and moves at the rate of 60 feet in a second: B weighs 300 pounds and moves at the rate of 10 feet per second: How are their momenta? Ans. *equal;* for $50\times 60=300\times 10$.

2. A weighs 7 lbs. and is moving with a velocity of 9 feet in a second; B weighs 5 lbs. and moves with a velocity of 11 feet in a second: What are their comparative momenta? Momentum of A : momentum of B$::7\times 9:5\times 11$; that is $63:55$ Ans.

3. Suppose the battering ram of Vespasian weighed 10,000 pounds, and was propelled with a velocity of 20 feet per second, and that this force was found sufficient to demolish the walls of Jerusalem. With what velocity must a 32 pound ball move to do the same execution?

The ball, in order to do the same execution as the battering ram, must have the same force, that is, the same momentum. Now the momentum of the battering ram is $10{,}000\times 20=200{,}000$; and this divided by 32 gives 6,250 for the number of feet per second the ball must move in order to have a momentum of 200,000 pounds.

4. Suppose a grain of light, moving at the rate of 192,000 miles per second, should impinge directly against a mass of ice, floating at the rate of one foot per second: what weight of ice would the light stop? Ans. 144822.857 lbs.; or more than 64 tons. (1lb. av.$=$7,000 grs.)

How is a force measured? How is a momentum estimated? *Example, in a cannon ball.*

5. The earth being 8000 miles in diameter, if a ball of the same density with the earth, $\frac{1}{10}$th of a mile in diameter, were placed at the distance of $\frac{1}{10}$th of a mile above the earth; what space would the earth move through to meet it? Ans. $\frac{1}{80,000,000,000,000}$th inch nearly.*

CHAPTER III.

OF THE LAWS OF MOTION.

25. THERE are three fundamental principles of motion, of most extensive application in Mechanics, which are called the Laws of Motion. They are remarkable examples of a happy generalization; but their very comprehensiveness renders them difficult to be understood by the young learner; nor can they be thoroughly mastered, in all their relations, until after considerable proficiency is made in the science of Mechanics. We shall endeavor to make them as plain as possible by a variety of illustrations.

26. FIRST LAW.—*A body continues always in a state of rest, or of uniform motion in a right line, till by some external force it is made to change its state.*

This law contains the doctrine of *Inertia*, expressed in four particulars. First, that unless put in motion by some external force, a body always remains at *rest;* secondly, that when once in motion, it *continues always in motion* unless stopped by some force; thirdly, that the motion arising from inertia, is always *uniform;* and, fourthly, that this motion is in *right lines.*

27. That a body at rest will continue at rest, is a consequence immediately arising from the inertia of matter. (Art. 12.)

If a large and a small body move towards each other in consequence of their mutual attractions, how much faster will the smaller body move than the larger?

State the *First Law* of motion. Mention each of the four particulars which this law embraces. How do we infer that a body at rest will continue at rest unless moved by some external force?

*In order to solve this question, the learner must bear in mind, that the two bodies would approach each other with equal momenta (Art. 8.); but that the space over which the earth would pass, would be as much less than that of the smaller body, as its quantity of matter was greater; and that the quantities of matter in spheres, are proportioned to the *cubes of their* diameters.

That a body in motion will continue to proceed uniformly along the right line in which it began to move, until it is acted upon by some external force, is inferred from the fact, that any deviation from uniform rectilinear motion, in a moving body, is observed to be owing to some *external force;* and that such deviation is diminished as such external force is withdrawn; hence, were it *entirely* withdrawn, the motion of the body would become altogether uniform, rectilinear, and perpetual. We may see approximations to such a state, in a ball rolled successively on the earth, on a floor, and on smooth ice. Although, on account of the numerous impediments to motion which exist at the surface of the earth, bodies are unable to maintain for any considerable time, the motion they have acquired, yet we see the first law of motion, so far as it respects the tendency of bodies to persevere in motion, fully confirmed in the continued and unaltered revolution of the heavenly bodies. These are impelled by no renewed forces, but revolve from age to age in an undeviating course, simply because they meet with no impediments.

28. We may see various exemplifications of this law in the occurrences that daily present themselves to our observation. And *first*, with respect to bodies at *rest*. Their tendency to remain at rest is seen, when a horse starts suddenly forward, and his rider is thrown backward. In consequence of the inertia of matter, before a body can be brought to the required velocity, this velocity must be impressed on every particle of matter it contains. Hence, the more numerous its particles, the greater is the resistance from inertia; that is, the resistance is proportioned to the quantity of matter. A vast weight may be moved on a horizontal rail way by a comparatively small force, provided it can be got into motion, with the required velocity. In transporting large quantities (eighty tons for instance,) of coal, the weight is distributed into a number of different cars, connected together by a loose chain, in order that the inertia of the several parts may be overcome successively.

29. In consequence of the inertia of matter, the motion applied to a body, does not instantly pervade the mass. In order to this, motion must be applied gradually, especially if the body is large; for if it is applied suddenly, it is frequently all ex-

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How do we infer that a body in motion tends to move uniformly and in a right line? Examples in a ball rolled on ice—in the motions of the *heavenly bodies?* Examples of inertia in riding—in loads transport*ed on a rail way.*

pended on a part of the mass, the cohesion is overcome, and the body is broken. This explanation may be applied to several familiar facts. When a team starts suddenly forward with a heavy load, the effort is either wholly ineffectual, or some part of the harness or tackling gives way. If we draw a heavy weight by a slender string, a slow and steady pull will move the weight, when a sudden twitch would break the string without starting the mass. The same principle applies to bodies already in motion. Thus, when a horse in a carriage starts suddenly forward, he may break loose as well when the carriage was previously in motion as when it was at rest. The inertia of a body is, in fact, the same whether the body is in motion or at rest, opposing the same resistance to its moving with increased velocity, as to its beginning to move from a state of rest.

30. Several singular phenomena result from the same cause, showing that *time* is necessary in order that motion communicated by impulse may pervade the entire mass. A pistol ball, fired through a pane of glass, frequently makes a smooth well defined hole, and does not fracture the other parts of the glass. Here, the momentum of the ball is communicated to the particles of glass immediately before it. Had the impulse been gradual, the same motion would have diffused itself over the whole pane, and every part would have felt the shock. A ball fired through a board delicately suspended, causes no vibration in the board. A cannon ball having very great velocity passes through a ship's side, and leaves but a little mark, while one with less speed splinters and breaks the wood to a considerable distance around. A near shot thus often injures a ship less than one from a greater distance. A soft substance, as clay or tallow, may be fired through a plank before the motion has had time to diffuse itself through the contiguous parts The whole momentum being concentrated upon the part immediately before the body, the cohesion of that part is destroyed.

31. *Secondly*, let us consider the effects of Inertia as it respects bodies in *motion*. All bodies in contact with each other acquire a common motion; as, for example, a horse and his rider, a ferry boat and its passengers, a ship and every thing

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Does motion instantly pervade the mass? Examples in teams starting from rest or in motion, in firing a pistol ball, and cannon ball, or soft substances. Give examples of bodies in contact, which acquire a *common motion*.

within it, the earth and all things on its surface. Whenever either of these bodies stops suddenly, the movable bodies connected with it are thrown forward. Were the revolution of the earth on its axis to be suddenly arrested, the most dreadful consequences would ensue; every thing movable on its surface, as waters, rocks, cities, and animals, not receiving, instantaneously, this backward impulse, would fly off eastward, in promiscuous ruin. Were the diurnal motion of the earth, however, very gradually diminished, until it finally ceased, so that time should be afforded to communicate the loss of motion by slow degrees to the bodies on its surface, no such effects would take place. If a passenger leaps from a carriage in rapid motion, he will fall in the direction in which the carriage is moving at the moment his feet meet the ground; because his body, on quitting the vehicle, retains, by its inertia, the motion which it had in common with it. When he reaches the ground, this motion is destroyed by the resistance of the ground to the feet, but is retained in the upper and heavier part of the body, so that the same effect is produced as though the feet had been tripped. *Coursing* owes all its interest to the instinctive consciousness of the nature of inertia, which seems to govern the measures of the hare. The greyhound is a comparatively heavy body moving at the same or greater speed in pursuit. The hare *doubles*, that is, suddenly changes the direction of her course, and turns back at an oblique angle with the direction in which she had been running. The greyhound, unable to resist the tencendy of its body to persevere in the rapid motion it had acquired, is urged forwards many yards before it is able to check its speed and return to the pursuit. Meanwhile the hare is gaining ground in the other direction, so that the animals are at a very considerable distance asunder when the pursuit is recommenced. In this way a hare, though much less fleet than a greyhound, will often escape it.*

32. *Thirdly*, bodies, in consequence of their inertia, have a tendency to move over equal spaces in equal times; that is, to move *uniformly*. In a ball rolled on ice, in a pendulum continuing to vibrate after the moving force is withdrawn, and in numerous cases similar to these, we observe both in nature and

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Effects of inertia on bodies suddenly stopped. Examples, in the earth suddenly losing its diurnal motion—in leaping from a carriage—in coursing. Examples of the tendency of bodies to move *uniformly*—in a ball rolled on ice—in a pendulum.

* Lardner.

art this tendency to uniform motion; but in all these cases, the motion is not absolutely uniform, but is more or less retarded by the resistances encountered. A much nearer approximation to the truth is obtained by means of an apparatus called *Atwood's Machine*. (Fig. 2.) Its construction, omitting some parts not essential to the principle, is as follows. The triangular base and upright pillars (which are usually of mahogany) constitute the frame, which is surmounted by a horizontal table or plate of wood A B, perforated with several holes. C is a vertical wheel, which, by a contrivance called friction wheels, (not represented in the figure,) is made to revolve with the least possible resistance from friction. D and E are two weights exactly equal, and connected by a slender string passed over the wheel C. F G is a perpendicular scale graduated into inches from top to bottom, extending from 0 to 60 or 70, according to the height of the machine. H is a movable ring which slides up and down on the scale, and K is a brass plate sliding in the same manner. There are also sometimes connected with the machine, a pendulum, and such parts of a clock as are necessary for beating seconds, in order that the time of each experiment may be accurately noted.

Fig. 2.

33. A great variety of the principles of motion, may be established by means of this apparatus, but we are at present concerned only with the method of showing, that a body when once put in motion continues, by inertia, to move *uniformly*, after the moving force is withdrawn. It is obvious that the weights D and E balance each other, and consequently that the power of gravity is entirely removed from D, so that it is at liberty to obey the full and exclusive influence of any force that may be applied to it. If, therefore, an impulse be given, by the finger, for example, to D, when at the top of the scale, it ought in conformity to the law under consideration to move uniformly

Describe *Atwood's Machine*. How is the tendency of bodies to move *uniformly, proved by this apparatus*?

along down the scale, passing over the same number of inches in each successive second. Such appears to be the fact; but in order to give a still greater precision to the experiment, a small brass bar is laid on D, which communicates motion to it, accelerating its progress until it comes to the brass ring H, where the bar lodges and the weight proceeds on with the velocity required. This velocity is found to be uniform; that is, the weight D after it leaves the ring passes accurately over the same number of inches on the scale in each successive second.

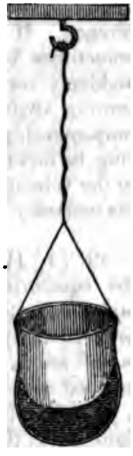
34. *Fourthly*, moving bodies have a constant tendency to move in *right lines*. In nature, there occur, indeed, but few examples of rectilinear motion, but almost every moving body describes a curve. Thus, the heavenly bodies move in ellipses or ovals; bodies thrown into the air describe a curve called a parabola; or if their direction is so altered by a resisting medium that their path is no longer a parabola, it is still changed to some other curve; and a ship sailing across the ocean, describes a curvilinear path on the surface of the earth. The waving of trees and plants, the courses of rivers, the spouting of fluids, and the motions of winds and waves, are likewise more or less curvilinear. Bodies falling towards the earth by gravity, present almost the only examples we observe in nature of a motion purely rectilinear; and this is so only in appearance. But notwithstanding the deviations from a right line, observable in actual motions, yet we find that there is always some extraneous cause in operation which accounts for such deviations.

35. In consequence of this tendency of moving bodies to proceed in right lines, when a body revolves in a curve, around some center of motion, it constantly tends to fly off in a straight line which is a tangent* to its orbit. The force which thus carries a body off from the center of motion, is called the *centrifugal force*. A stone from a sling, water escaping from the circumference of a revolving wheel, and water receding from the center of a tumbler or pail when the vessel is whirled, are familiar instances of the tendency of bodies when revolving in circles to fly off in straight lines. If a pail, containing a little water, be hung up by the ears, by a cord suspended from the ceiling

How is the tendency of bodies to move in *right lines* proved? Are natural motions usually rectilinear? Examples. Define *centrifugal force*. Examples in a sling,—in a water pail suspended and whirled.

* A *Tangent* is a straight line which touches the circumference of a circle.

Fig. 3.



of a room, on turning the pail and twisting up the cord, and then suffering it to untwist so as to give a rapid revolution to the pail, the water will rise on the sides of the vessel, and, if the motion be sufficiently rapid, it will be thrown out of the vessel in lines which are tangents to the surface of the vessel. If a glass vessel of suitable size and shape* be substituted for the pail, the experiment is observed to better advantage. Such a vessel is represented in the annexed figure.

36. The action of the centrifugal force may be studied still more advantageously by means of the apparatus called the Whirling Tables. These consist of two small circular tables, to which (by means of a crank) is communicated a horizontal revolution around their centers. Bodies laid on the tables in different ways, are made to participate in their rotary motions, and thus the laws of the centrifugal force may be observed. By means of this apparatus, the following propositions are established.

37. (1.) The centrifugal force of bodies revolving in a given circle, is proportioned to their *densities* or *specific gravities*. If quicksilver, water, and cork, be whirled together in a tub or vessel, these bodies arrange themselves in the inverse order of their specific gravities, so that the cork will be at the least, and the quicksilver at the greatest distance from the center of the vessel.†

38. (2.) When bodies revolve in the same circle with different velocities, the centrifugal forces are proportioned to the *squares of the velocities*. By doubling the velocity of a revolving body its centrifugal force is quadrupled; and ten times a former velocity, gives one hundred times the former centrifugal force. Millstones, revolving horizontally, communicate their circular motion to the corn that is introduced between them, near the

Describe the *Whirling Tables.* How are bodies placed in experiments on centrifugal force? State the law in relation to *density.* Examples, in quicksilver, water, and cork. State the law in relation to different velocities. How much is the centrifugal force of a body, revolving at a given distance from the center increased, by increasing its velocity ten times.

* A large bell glass receiver belonging to the air pump, answers well for this purpose.

† *This experiment may be conveniently performed in the suspended vessel, Fig. 3.*

center. The corn, by the centrifugal force which it gradually acquires, recedes from the center and passes out at the circumference. If too great a velocity be given to millstones, they sometimes burst with violence. A horse in swift motion, on suddenly turning a corner, throws his rider; and a carriage turning swiftly is overset on the same principle. In feats of horsemanship, when the equestrian rides rapidly round a small ring, he inclines his body inwards in different degrees, according to the velocity with which he is moving, and thus counteracts his tendency to fall outwards by the centrifugal force.

39. (3.) Hence, when spherical bodies revolve on their axes, the equatorial parts being farther from the center of motion, and consequently moving faster than the other parts, have a proportionally greater centrifugal force. If the revolving body is soft so as to yield, it is elevated in the equatorial and depressed in the polar parts. Thus a mass of clay revolving on a potter's wheel, swells out in the central parts and becomes flattened at the two ends. The earth itself, by its figure, which is an oblate spheroid,* the diameter which passes through the equator being about 26 miles greater than that which passes through the poles, indicates the operation of this principle; and the planet Saturn, which has a far more rapid revolution on its axis, indicates the same modification of its figure in a still higher degree, being strikingly elevated at the equator and depressed at the poles. Let the circle in Fig. 4. represent a section of the earth, AB being the axis on which it revolves. This rotation causes the matter, which composes the mass of the earth, to revolve in circles round the different points of the axis as centers, at the various distances at which the component parts of the mass are placed. As they all revolve with the same angular velocity, they will be affect-

Fig. 4.

Examples of centrifugal action in millstones—in turning a corner swiftly—in feats of horsemanship. State the effects of centrifugal action on the figure of spherical bodies. Examples, in the earth and planets. Illustrate by figure 4.

* A spheroid differs from a globe or sphere, in being flattened in one direction and *lengthened in* the other. The spheroid is *oblate* when its figure is flattened like an *orange*, and *prolate* when elongated like a lemon.

ed by the centrifugal forces, which will be greater or less in proportion as their distances from the center are greater or less; consequently, the parts of the earth which are situated about the equator, Q, will be more strongly affected by centrifugal forces than those about the poles A, B: the effect of the difference has been, that the component matter about the equator has actually been driven farther from the center than that about the poles, so that the figure of the earth has swelled out at the sides, and appears proportionally depressed at the top and bottom, resembling an orange in shape.

40. The centrifugal force of the earth's rotation also affects detached bodies on its surface. If such bodies were not held upon the surface by the earth's attraction, they would be immediately flung off by the whirling motion in which they participate. The centrifugal force, however, really diminishes the effect of the earth's attraction on these bodies, or what is the same, diminishes their weight, so that, were a body weighing 289 pounds at the equator, carried to the north pole, it would there weigh 290 pounds, if it were at the same distance from the center of the earth: but being nearer the center when at the pole than at the equator, it gains still more weight, so that, from both causes, there is a gain of one pound in 194. If the earth were not revolving on its axis, the weight of bodies in all places equally distant from the center would be the same. [illegible]

[illegible]

faster than it is, the centrifugal force would, at the equator, be equal to the power of gravity, and all bodies there would entirely lose their weight; and if the earth were to revolve still quicker than this, they would all fly off.

41. The consideration of centrifugal force proves, that if a body be observed to move in a curvilinear path, some efficient cause must exist which prevents it from flying off, and which compels it to revolve round the center. Thus the bodies of the solar system are constantly impelled or drawn towards the sun by a force which we denominate gravity. If this force did not act constantly, they would resume their motion in the right line in which they were originally projected, when they were first launched into space, and would continue moving in it forever.

42. SECOND LAW.—*Motion, or change of motion, is proportional to the force impressed, and is produced in the right line in which that force acts.*

First, motion is proportional to the force impressed. This is very satisfactorily shown by means of Atwood's Machine. (Fig. 2.) When the box D is loaded with bars of different weights, (the bars being left on the ring, H, as in Art. 32,) the box descends along the scale, in consequence of the motion given it by the bar, with velocities exactly proportional to the weights of the bars respectively.

43. *Secondly*, motion is in the *direction* of the force impressed. Notwithstanding the diversity of motions to which every terrestrial body is constantly subject, the effect of any force to produce motion, is the same, when the spectator has the same motion with the body, as though that body were absolutely at rest. In other words, all motions are compounded so as not to disturb each other; each remaining, relatively, the same as if there were no others. If we are in a ship, moving equably, any force which we can exert will produce the same motion relative to the vessel, whether it be or be not in the direction of the vessel's motion. If we stand on the deck, supposed to be level, and roll a body along it, the same effort will produce the same velocity along the deck whether the motion be from head to stern, or from stern to head, or across the vessel. Also a

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What is the Second Law of Motion? How is the first part of this law proved by experiment? Is the effect of a force altered by the body's *being previously in motion?* Example, on board of vessel. Case of a ball *rolled in different directions.*

body dropped from the top of the mast will not be left behind by the motion of the ship, but will fall along the mast as it would if the mast were at rest, and will reach the foot of it at the same time. If a body be thrown perpendicularly upwards, it will rise directly over the hand and fall perpendicularly upon it again; and if it be thrown in any other direction, the path and motion relative to the person who throws it will be the same as if he were at rest.

44. Since, according to the second law of motion, the change of motion is proportional to the force impressed, it follows that *the smallest force is capable of moving the largest bodies*. Agreeably to this doctrine, a blow with a hammer upon the earth ought to move it, and that it would do so may be inferred from the following reasons.

(1.) We can conceive the earth to be divided into parts so small, that the blow would produce upon one of them even a *sensible* motion. Then it would produce on two of the parts half as much velocity; and upon all the parts together a velocity as much less than upon one, as their number was greater than unity. This velocity might be appreciable in numbers, although too small to be observed by the senses.

(2.) Very heavy weights may be actually put in motion by small forces. Leslie asserts that a ship of any burden may in calm weather and smooth water, be gradually pulled along, even by the exertions of a boy.

(3.) The repetition of very small blows, finally produces sensible effects upon large bodies. The wearing away of stone by the dropping of water, the abrasion of marble images by the kisses of pilgrims, and especially, the demolition of the strongest fortresses by repeated blows of the battering ram, are examples of the powerful effects produced by small impulses, each of which must have contributed its share, since the addition of any number of nothings is nothing still.

45. Third Law.—*When bodies act upon each other, action and reaction are equal and in opposite directions.*

If I strike one hand upon the other at rest, I perceive no difference in the sensations experienced by each. The resis-

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Case of a body dropped from mast head,—of a body thrown directly upwards—or in any other direction. Is the smallest force capable of removing the largest body? Effect of a blow with a hammer on the earth. Three reasons stated in favor of the doctrine. What is the Third Law of Motion? *Example, one hand struck upon the other.*

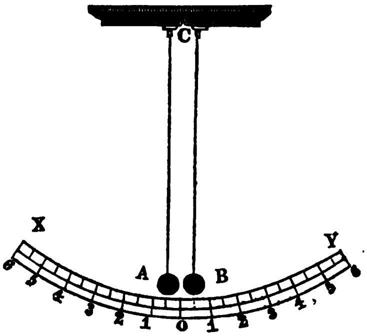
tance to the hand which gives the blow is equal to the impulse given. A boatman presses against the bank with his oar, and receives motion in the opposite direction, which being communicated through him to the boat, makes it recede from the shore. He strikes the water, the reaction of which, at every impulse, carries the boat forward in the opposite direction. An infirm old man presses the ground with his staff, and thus by lightening the pressure on his lower limbs, makes his arms perform a part of the labor of walking. A bird beats the air with his wings, and by giving a blow whose reaction is more than sufficient to balance the weight of his body, rises with the difference. When the wings are small and slender, as those of the humming bird, and disproportioned to the weight of the body, the defect is compensated by more frequent blows, giving nimble motions suited to their short but swift excursions, while the long wings of the eagle are equally fitted, by their less rapid, but more effectual blows, for their distant journeys through the skies. Hence, propelling and rowing a boat, flying, and swimming, are processes analogous to each other, depending on the principle of reaction.

46. If a man stands in a boat and pulls upon a rope which is fastened to a post on the shore, the force of the man is expended on the post in one direction, and the post, by its reaction, draws the man in the opposite direction, namely, towards the shore. Call the man A, and let another man B, take the place of the post. If B pulls with a force just equal to that of A, he will do nothing more than what the post did before, and therefore the two men together will bring the boat ashore no sooner than A would have done it alone in the former case. If A pulls with more force than B, he pulls B towards him and the reaction, or the force which carries the boat ashore, is the same as before, namely the force of B. If B were to pull with more force than A, he would pull A out of the boat, were not A attached firmly to the boat, in which case the velocity of the boat would be augmented. By attentively considering this and all analogous cases, we shall perceive, that whenever two bodies act against each other, they give and receive equal momenta, and the momenta being in opposite directions, it follows, that bodies do not alter the quantity of motion they have, estimated in a given direction, by their mutual action on each other.

Why does pressing the bank with an oar move a boat? Why does striking the water do the same? Why does a staff aid in walking? *Explain* the philosophy of flying, and swimming. Case of a man in a boat *pulling at a rope* which is fastened to a post.

47. These familiar illustrations may serve to give a general notion of the doctrine of action and reaction, as contained in the third law of motion; but this law is susceptible of more precise experimental proof by means of the following apparatus. (Fig. 5.) Two equal bodies, whose quantities of matter, or weights are respectively represented by A and B, are suspended contiguous to each other by strings of equal length. A is pulled from its pependicular position, and let fall upon B at rest. The space through which each body passes in a given time, as indicated by the graduated arc XY, is a measure of its velocity, and, in all cases velocity multiplied into the weight, is a measure of the momentum. (Art. 22.) From experiments with this apparatus, the following truths are established: (1.) That, when A is *equal* to B, the two bodies move together after impact with half the velocity of A before impact; and since the quantity of matter in both is double that of A, the two bodies moving with half the velocity of one of them, have the same momentum, that is, the same after impact as before, and consequently as much motion as A imparted to B by its *action*, just so much B took from A by its *reaction*. (2.) That, when A is *greater* than B, it still holds true that the momentum of the mass composed of both bodies united, is the same after impact as before: consequently B extinguishes in A just as much motion as it receives from it. (3.) That when the two bodies move in *opposite* directions, the quantity of motion after impact is equal to the *difference* of their momenta before impact. Thus if A and B are equal, and they meet with equal velocities, each receiving what it gives in an opposite direction, both are brought to a state of rest. If B has half the velocity of A then it will extinguish an equal amount in A, and will return in company with A with the same velocity as before.

Fig. 5.



How is the law of reaction established by experiment? Describe the apparatus. When A is let fall upon B at rest, (the two bodies being equal,) with what velocity do they move after impact? When A is greater than B, how is the momentum after the blow? How much motion does B extinguish in A? *When the two bodies meet from opposite directions how are their momenta after impact?*

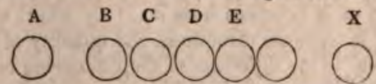
48. In order to understand the doctrine of the *collision of bodies*, it is necessary to advert to the distinction between *elastic and non-elastic* bodies. *Elastic bodies are such as when compressed, restore themselves to their former state.* If they restore themselves with a force which is equal to the compressing force, then they are said to be *perfectly elastic.* Sponge is a substance of the kind which possesses greater or less degrees of elasticty. Glass, ivory, marble, and steel, are among the most elastic substances of any with which we are acquainted. Two masses of lead, or earth, when struck together, scarcely rebound at all, and are therefore non-elastic. Air, when compressed, restores itself with a force equal to that which compresses it, and is therefore perfectly elastic; but most of the other elastic substances above mentioned, possess this property in an imperfect degree only.

In the experiments mentioned in Art. 47, the impigning bodies are supposed to be non-elastic.

49. *In the collision of perfectly elastic bodies, the velocity lost by the one and gained by the other, is* TWICE *that which it would have been, had they been perfectly non-elastic.*

Let us take the case of two equal bodies, as two ivory balls, supposing each to be perfectly elastic, and calling one A and the other B. First, let A overtake B moving in the same direction; then B will move off with the original velocity of A, and A will move with that of B; that is, the two will interchange their velocities. Secondly, let the two bodies meet from opposite directions: each will return with the original velocity of the other. Thirdly, let A strike upon B at rest; then A will stop, and B will proceed with the motion A had before. Again, let us take the case of a *row* of equal elastic bodies, as

Fig. 6.



A will communicate its motion to B and stop; and thus each of the bodies will successively transmit its motion to the next body and be brought to rest, while the last body, X, will move off with the original velocity of A.

When is a body said to be *elastic?* When *perfectly elastic?* Examamples of elastic bodies. Also of non-elastic. State the proposition respecting the collision of two perfectly elastic bodies. Case of two equal bodies, A overtaking B moving the same way. Case where they *meet from opposite* directions. Case of a *row* of equal bodies, motion *being communicated* to the series from the first body.

50. It is a general law in the material word, that no body loses motion in any direction, without communicating an equal quantity to other bodies in that same direction; and conversely, that no body acquires motion in any direction, without diminishing the motion of other bodies by an equal quantity, in the same direction.

This law of motion applies not only to the *impact* of bodies, but to every case in which one body acts upon another. It holds good, not only when bodies come into actual contact, but when they act upon one another at any distance whatever. A body A, for instance, is sustained by another body B, and both bodies remain at *rest;* if the pressure exerted by the two bodies were not equal, it is evident that some *motion* would ensue; which is contrary to the supposition. If motion does ensue, then the case becomes, in a great measure, analogous to that of *impact;* and the effects produced, estimated in a similar manner, are found to observe the same law. The *mutual attractions* of bodies are also subject to this law. Thus if two equal magnets, connected with two equal and similar pieces of cork, be made to float upon the surface of water, as soon as they come within the sphere of attraction, they are observed to move towards each other in a right line, with equal velocities, and consequently with equal momenta; and as the resistance which each body meets with from the fluid, is evidently the same, we infer that their actions upon each other are equal.

51. Hence it follows, that the sum of the motions of all the bodies in the world, *estimated in one and the same line of direction*, and always the same way, is eternally and invariably the same. Whatever motion, therefore, one body receives towards another, whether it is drawn towards it by attraction, or by a rope, or by any other method, precisely the same quantity of motion it imparts to the other body in the opposite direction. If a man in a boat pulls at a rope attached to another boat of equal weight, the boats will move towards each other with equal velocities; but a man in a boat pulling a rope attached to a large ship seems only to move the boat, but he really moves the ship a little, although its velocity is as much less than that of the boat as its weight is greater. A pound of lead and the earth attract each other with equal forces, and the two bodies approach each other with equal momenta. (See Art. 8.)

Is the law of action and reaction confined to cases of impact? How exemplified in pressure—in mutual attractions? What is the sum of the motions of all bodies *in the* universe estimated in one and the same *line of direction? Case of* a boat and a ship—of a pound of lead and the *earth.*

52. Since momentum is proportioned to the joint product of the velocity and quantity of matter, a great momentum may be obtained, either by giving a slow motion to a great mass, or a swift motion to a small body. A striking illustration of this is afforded by example 4. p. 20, where, on the supposition that a grain of light moving with its usual velocity, were to impinge directly against a mass of ice floating at its ordinary slow rate, the grain of light would be competent to stop about sixty five tons of ice. Islands of ice move with such vast momentum, that they instantly demolish the largest ship of war if it comes in their way.

53. If a body in motion strikes a body at rest, the striking body must sustain as great a shock from the collision as if it had been at rest, and struck by the other body with the same force. For the loss of force which it sustains in one direction, is an effect of the same kind as if, being at rest, it had received as much force in the opposite direction. If a man walking rapidly, or running, encounters another standing still, he suffers as much from the collision as the man against whom he strikes. When two bodies moving in opposite directions meet, each body sustains as great a shock as if, being at rest, it had been struck by the other body with the united forces of both. For this reason, two persons walking in opposite directions, receive from their encounter a more violent shock than might be expected. If they be of nearly equal weight, and one be walking at the rate of three and the other of four miles an hour, each sustains the same shock as if he had been at rest, and struck by the other running at the rate of seven miles an hour. This principle accounts for the destructive effects arising from ships running foul of each other at sea. If two ships of 500 tons burden encounter each other, sailing at ten knots an hour, each sustains the shock which, being at rest, it would receive from a vessel of 1000 tons burden sailing ten knots an hour. It is a mistake to suppose, that when a large and a small body encounter each other, the smaller body receives a greater shock than the larger. The shock which they sustain is the same; but the larger body is better able to bear it. When the fist of a pugilist strikes the body of his antagonist, it sustains as great a shock as it gives; but the part being more fitted to receive the

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In what two ways may a great momentum be gained? Example, in a grain of light striking an island of ice. Example of one man encountering another. Account for the destructive effects of ships running foul of *each other* at sea. Does the smaller body receive a greater shock than *the larger?* Why does the blow given by the fist hurt the person struck *more than the* assailant?

blow, the injury and pain are inflicted on his opponent. This is not the case, however, when fist meets fist. Then the parts in collision are equally sensitive and vulnerable, and the effect is aggravated by both having approached each other with great force. The effect of the blow is the same as though one fist, being held at rest, were struck with the combined force of both.*

54. The question may be asked, why are the effects so much more injurious to fall from an eminence upon a naked rock, than upon a bed of down? In both instances our fall is arrested, and we sustain a contrary and equal reaction; yet in the one case we might suffer hardly any injury, while in the other, we should be bruised to death. The reason of the difference is this: when we fall on a bed of down, the resistance is applied *gradually*; when we fall on a rock it is applied *instantaneously*. We do not strike the bed with the same force that we do the rock; we move along with the bed, and of course do not lose our motion at once, and we receive in the opposite direction merely what we lose. A violent blow, if equally diffused over the human body, may be sustained without injury. Thus, if an anvil be laid on the breast, a man may receive on it a heavy blow with a great hammer with impunity.

55. There are many instances where action and reaction mutually destroy each other, and no motion results. Thus, when a child stands in a boat and pulls by a rope attached to the stern, he labors in vain to make the boat advance. Dr. Arnott tells us of a man who attached a large bellows to the hinder part of his boat, with the view of manufacturing a breeze for himself, being ignorant that the reaction would carry the boat backward as much as the impulse of artificial wind carried it forward. A force which begins and ends with a machine has no power to move it.

56. The three Laws of motion, which, on account of their extensive application to the phenomena of motion, we have endeavored to render familiar to the learner by a variety of illustrations, are to be regarded as the fundamental principles of mechanics. Their truth rests on three different kinds of evidence:

Why are the effects so much more injurious to fall upon a naked rock than upon a bed of down? Case of a violent blow diffused over the whole body. Examples, where action and reaction mutually destroy each other. Upon what three kinds of evidence rests the truth of the three Laws of Motion?

*Lardner.

1. They are conformable to all *experience* and *observation*.

2. They are confirmed by various accurate *experiments*.

3. The conclusions deduced from them have always proved true in fact, without exception.

CHAPTER IV.

OF VARIABLE MOTION.

57. When a moving body is subjected to the energy of a force which acts on it without interruption, but in a different manner at each instant, the motion is called in general *variable motion*. We have instances of variable motion in the action of gunpowder on a ball while it is passing through the barrel of a gun, and in the action of the wind on the sails of a ship. In each of these cases, the velocity of the moving body is constantly augmented, yet the degree of augmentation is diminishing until it finally ceases.

When a moving body receives each successive instant the same increase of velocity, it is said to be *uniformly accelerated*. If a small wheel were revolving without resistance, and, at the end of every second, I should apply a given impulse, the wheel would be uniformly accelerated; for, by its own inertia, it would retain all its previous motion, and, by the second law of motion, the repetition of the same force, at equal intervals, would increase its velocity at a uniform rate. If the intervals at which this force was repeated were indefinitely diminished, the same kind of effect would take place; and the same would evidently be the case, were the force to operate without cessation. Such a force is that of *gravity*, the consideration of which will be pursued in the following sections.

Falling Bodies.

58. In consequence of gravity, all bodies near the earth fall towards its center. We are not to infer from this fact, that there is any peculiar force, (like that of a large magnet for example,) residing at the center, but merely that the effect

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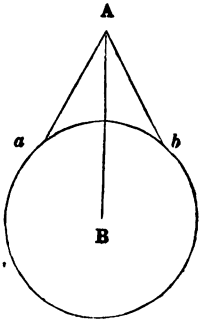
Define *Variable Motion*. Examples, in a musket ball—in the action of the wind upon a sail. When is a moving body said to be uniformly accelerated? Example, in a revolving wheel. Gravity a constant force. *In what direction* do bodies fall by gravity? Why towards the center of the earth? Explain by figure 7.

of the earth, taken as a whole, is the same as though its matter were condensed into the center. Thus in Fig. 7, if we consider how a body at A would be attracted towards the earth, recollecting that every particle of matter in the earth exerts its share in the effect, we shall perceive that while the matter on one side would attract it to the right of the line AB, the matter on the other side would attract it to the left of the same line; consequently, both together would carry it directly forward in the line AB towards the center; and the same would be true were the body A placed in any other point exterior to the earth.

Fig. 7.



The leading truths respecting falling bodies will be stated in the form of propositions, which the learner is requested to commit accurately to memory. The illustrations subjoined to each, will, it is believed, render perfectly intelligible whatever may not be fully understood from the proposition as enunciated.

59. I. *The spaces described by bodies falling from a state of rest under the influence of gravity, are proportioned to the* SQUARES OF THE TIMES, *during which they are falling.*

Thus, if a body be let fall from the top of a tower, or from the brow of a precipice, it will fall in two seconds not merely *twice* as far as in one second, but *four* times as far; in three seconds *nine* times as far; in ten seconds *one hundred* times as far; and so on, the spaces being proportioned, not simply to the times 1, 2, 3, and 10, but to their squares, 1, 4, 9, and 100.

It is found by actual experiment that the space through which a body falls in one second from a state of rest, is $16\frac{1}{12}$ feet. Hence, it is easy to estimate the space corresponding to any other time; for the space belonging to two seconds must be $4\times16\frac{1}{12}$, or $64\frac{1}{3}$ feet; to three seconds, $9\times16\frac{1}{12}$, or $144\frac{3}{4}$ feet; and to ten seconds, $100\times16\frac{1}{12}$, or $1608\frac{1}{3}$ feet. To find the number of feet therefore, through which a body falls, the time being known, we have the following RULE. *Multiply the square of the number of seconds by* $16\frac{1}{12}$.

State the proposition respecting the relation between the *spaces* and *times*. How much farther will a body fall in two seconds than in one? Give the *rule for the number of feet* through which a body falls in a given time.

Ex. A body has been falling 7 seconds: through what space has it fallen? Ans. $788\frac{1}{12}$.

60. A body descending by gravity is in the same situation as a ball rolled on smooth ice, which should receive a new impulse every moment. Retaining all its previous motion and receiving more continually, its speed would shortly become very great; and were these new accessions of velocity without intermission and uniform (as is actually the case with gravity) the velocity acquired would be proportioned to the time the ball had been moving; so that at the end of two seconds it would be twice as great as at the end of one second; at the end of ten seconds ten times as great; and so on.

61. It appears from the foregoing principle, that the progress of a falling body is rapidly accelerated. In nature, however, the resistance of the air prevents a body which falls through it, from acquiring so great a velocity as it would otherwise do; still we see indications of the principle of acceleration, in the impetuosity with which bodies fall from any considerable height above the earth. Meteoric stones falling from the sky, sometimes bury themselves deep in the ground. Aeronauts that have fallen from balloons have been dashed in pieces. It is, however, a rare occurrence to see a body falling from any great height *perpendicularly;* most instances of accelerated motion which come under our observation, are bodies falling down *inclined planes,* where the same law of acceleration prevails. A fragment of rock descending from the side of a mountain, has its speed augmented as it goes, until its momentum becomes irresistible, and large trees are prostrated before it.

62. II. *If a body after it has fallen from rest, through any space, should then cease to receive any farther impulse from gravity, but should proceed on uniformly with the last acquired velocity, it would describe* TWICE *the space in the same time as that during which it has fallen to acquire that velocity.*

Thus, at the end of *one* second, having fallen $16\frac{1}{12}$ feet, it would have acquired a velocity which, in the next second,

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How is the effect of gravity illustrated by the motion of a ball on smooth ice? Do falling bodies rapidly increase in velocity? What hinders this increase? Examples, of the impetuosity of falling bodies. Do we often meet with bodies falling from a great height perpendicularly? Case of a rock descending a mountain. State the proposition respecting the motion of a body proceeding with the last acquired velocity.

would carry it $32\frac{1}{6}$ feet; at the end of *four* seconds, its space being $(4^2 \times 16\frac{1}{12} =)\ 257\frac{1}{3}$, it would, without any farther impulse descend during the next four seconds $514\frac{2}{3}$ feet.

63. III. *The spaces described by falling bodies are also proportioned to the squares of the velocities which they acquire in falling over those spaces.*

Ex. 1. Through what space must a body fall to acquire a velocity of 60 feet per second? In falling from rest $16\frac{1}{12}$ feet a body acquires a velocity of $32\frac{1}{6}$ feet; therefore, the square of the velocity acquired, that is, the square of $32\frac{1}{6}$, will bear the same ratio to its space, namely $16\frac{1}{12}$ feet, that the square of 60 bears to the space required; that is, $(32\frac{1}{6})^2 : 16\frac{1}{12} :: (60)^2 : 55.96$ feet. Ans.

Since $(32\frac{1}{6})^2 = (2 \times 16\frac{1}{12})^2 = 2^2 \times 16\frac{1}{12} \times 16\frac{1}{12}$, by dividing the two first terms by $16\frac{1}{12}$ we have $2^2 \times 16\frac{1}{12} : 1$, that is, $64\frac{1}{3} : 1$; hence to find the space from the velocity, we derive the following

RULE: *Divide the square of the velocity by* $64\frac{1}{3}$.

Ex. 2. From what height must a body fall to acquire a velocity of 50 feet per second? Ans. 38.86 feet.

Ex. 3. What velocity would a body acquire by falling 500 feet?

By the Rule. $\frac{V^2}{64\frac{1}{3}} = 500$; hence $V^2 = 500 \times 64\frac{1}{3} = 32166\frac{2}{3}$,

therefore $V = \sqrt{32166\frac{2}{3}} = 179.35$ feet per second.

64. As in the *descent* of a body, the force of gravity generates equal increments in equal times, so in its *ascent*, equal portions of velocity will be destroyed in equal times; that is, as a body is uniformly *accelerated* as it falls, so it is uniformly *retarded* as it rises. Hence,

IV. *If a body be projected perpendicularly upwards, with the velocity which it has acquired in falling from any height, it will rise to the height from which it fell, before it begins to descend again. It will also occupy the same time in rising as in falling.*

Ex. 1. To what height will a body rise, when projected perpendicularly upwards with a velocity of 120 feet per second?

How far would it move the second second with the velocity acquired during the first? How far in 4 seconds, having fallen 4? State the relation between the spaces and the acquired velocities. Give the rule for finding the space from the acquired velocity.

As it will rise to the same height as that from which it must have fallen to acquire this velocity, we have only to find this space. According to proposition III, $\frac{(120)^2}{64\frac{1}{3}}=223.8$ Ans.

Ex. 2. How high will a body rise when thrown perpendicularly upwards with a velocity of 100 feet per second? Ans. 155.4 feet.

65. The law of descent of falling bodies, as enunciated in proposition I., (Art. 59.) goes on the supposition that the body begins its descent from a state of rest, and that it afterwards receives no impulse from any force beside gravity; but we may have occasion to estimate the motion of a falling body which receives, either at first or during its descent, an impulse from some extraneous force. In this case we must add the amount of the impulse to the ordinary force of gravity, as expressed in the following proposition.

V. *The space described in a given time by a body projected downwards with a given velocity, is equal to the space which would be described with that velocity continued uniformly for that time, together with the* SPACE *through which a body would fall from rest by the action of gravity for the same time.*

Ex. 1. A body is *projected* downwards with the velocity of 30 feet in a second: how far will it fall in 4 seconds?

First, by a uniform motion of 30 feet for four seconds, the body would describe - - - - - 120 feet.

Secondly, by gravity it would, in the same time describe - - - - - - - - $257\frac{1}{3}$

Hence, the entire space is - - - $377\frac{1}{3}$ feet.

Ex. 2. A body after falling 3 seconds passes by a window in a tower, from which a person standing in the tower, gives it a blow downwards, which increases its velocity 20 feet per second, after which it falls during 2 seconds more, and then reaches the ground: what is the height from which it fell?

First, the descent by gravity for 5 seconds, is - $402\frac{1}{12}$ feet.

Secondly, the uniform motion of 20 feet for 2 seconds is - - - - - - - - 40

Whole space - - - - - - $442\frac{1}{12}$ feet.

State the case of a body thrown upwards. How high will it rise? *What time* will it occupy in rising? State the proposition respecting *a body projected* downwards with a given velocity.

Ex. 3. Suppose a body to be projected downwards with a veloctiy of 17 feet per second: how far will it fall in 5 seconds? Ans. $487\frac{1}{12}$ feet.

Questions on Falling Bodies.

1. From a black cloud a flash of lightning was observed, and 12 seconds afterwards it began to rain: on the supposition that the rain began to descend on the instant of the flash, what was the *height* of the cloud? Ans. 3216 feet.*

2. A body fell into a well which was 250 feet deep: *How long* was it in falling, and what *velocity* did it acquire? Ans. *Time*=3.942 seconds; *Velocity*=126.82 feet per second. (See Art. 63. Ex. 3.)

3. Wishing to ascertain the difference in the depth of two wells, I dropped a pebble into one of them, and heard it strike the water in 6 seconds; and then into the other, and heard it strike in 10 seconds; what was the difference in their depths? Ans. $1029\frac{1}{3}$ feet.

4. A boy wishing to know the height of his kite, found that he could just send an arrow to it, by giving to the arrow the velocity of 125 feet per second. What was the *height* of the kite? Ans. 242.9 feet.

5. From the top of a tower, a boy knocked his ball perpendicularly upwards. After 6 seconds it returned, when he gave it a blow downwards, which increasing its velocity 10 feet per second, it reached the ground in 4 seconds after it received the downwards blow: what was the height of the tower? Ans. $623\frac{1}{3}$ feet.

66. The laws of falling bodies are susceptible of very accurate experimental proof, by means of Atwood's Machine. (Art. 32.) Before the invention of this apparatus, there were two difficulties in the way of such a verification, namely, the *little time* occupied in descending through such perpendicular heights as the experimenter can command, and the *resistance of the air*, which, when the velocity becomes great, acts as a powerfully retarding force. We can rarely command a perpendicular eminence of more than 400 feet, and yet the time of passing over this space is only about five seconds, a period too short to enable us to mark distinctly the respective rates at which the successive intervals are described. Atwood's Machine affords the means of obviating both these difficulties, and of verifying the

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By what apparatus may the laws of falling bodies be verified?

* *No allowance is made in problems of this kind for resistance of the air.*

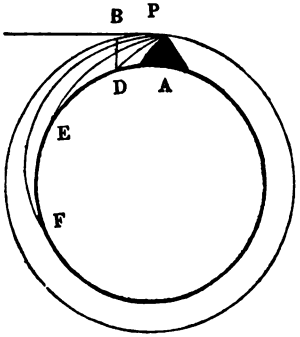
laws of falling bodies with great accuracy. The object of the machine, so far as it respects experiments on falling bodies, is to render the descent of bodies so *gradual*, that the relations between the times and spaces can be accurately observed. By recurrence to the figure, and to the description given in Art. 32, we shall readily see how this object is accomplished. The weights D and E are each equal to $31\frac{1}{2}$ ounces, and of course the quantity of matter in both is 63 ounces. Now, since one of these weights rises as the other descends, the force of gravity retards the one as much as it accelerates the other, and they are in effect the same as though they were entirely destitute of gravity. If a small weight, as one ounce, were let fall *freely* from the top of the machine, it would fall through this small space almost in an instant, and we should be unable to mark the rate at which it passed over the successive portions of the scale FG; but if it be laid on the weight D, it must carry D along with it; that is, it must make D descend, and E ascend, and therefore the motion belonging to one ounce, will be distributed through 64 ounces, and the velocity retarded in the same ratio. Consequently, the weight D will descend only $\frac{1}{64}$th part as fast as a body falling freely; and as a body falling freely descends about 16 feet, or 192 inches in one second, the weight D will descend $\frac{192}{64} = 3$ inches in the same time. The comparative progress of this weight, and of a body falling freely for several successive seconds, will be seen in the following table.

Time, in seconds,	1	2	3	4	5	6
Body falling freely, in feet,	$16\frac{1}{12}$	$64\frac{1}{3}$	$144\frac{3}{4}$	$257\frac{1}{4}$	$402\frac{1}{12}$	579
Do. in Atwood's Mach. in inc.	3	12	27	48	75	108

67. Hence it appears, that in 6 seconds, while a body would fall freely through 579 feet, it would in the same time descend only 9 feet in Atwood's Machine. But the latter is a uniformly accelerated velocity, and subject to the same laws as the former, and it may therefore be employed to investigate the laws of falling bodies. The results correspond remarkably with theory, so that when the instrument is well constructed and managed skilfully, the descending weight clicks upon the stage or brass plate K, at the very instant required.

What were the two difficulties in the way before this machine was contrived? What is the object of this machine? Explain how it renders the descent of bodies so slow. How far does the weight descend in one second? How far would a body fall freely in 6 seconds, and how far during the *same time in* Atwood's Machine?

Fig. 8.



68. It is not alone by the direct fall of bodies that the gravitation of the earth is manifested. The curvilinear motion of bodies projected in directions different from the perpendicular, is a combination of the effects of the uniform velocity which has been given to the body by the impulse which it has received, and the accelerated or retarded velocity which it receives from the earth's attraction. Suppose a body placed at any point P (Fig. 8.) above the surface of the earth, and let P A be the direction of the earth's center. If the body were allowed to move without receiving any impulse, it would descend to the earth in the direction of P A, with an accelerated motion. But suppose that at the moment of its departure from P, it receives an impulse in the direction PB ; then it would fall towards the earth, between the actions of the two forces, in the curve line P D. The greater the velocity of projection in the direction P B, the greater the sweep the curve will take. Thus it will successively take the forms P D, P E, P F, &c. until, when the velocity of projection is increased to a certain amount, the body will sweep quite clear of the earth, and like the moon revolve around it. Thus a cannon ball shot horizontally from the top of a lofty mountain, would go three or four miles. If there were no atmosphere to resist its motion, the same original velocity would carry it thirty or forty miles before it fell ; and if it could be despatched with about ten times the velocity of a cannon shot, the centrifugal force would exactly balance the force of gravity, and the ball would go quite round the earth. Such a velocity would carry the ball round the world in less than an hour and a half.*

69. Hence it is obvious, that the phenomenon of the revolution of the moon round the earth, is nothing more than the combined effects of the earth's attraction, and the impulse

How is gravity manifested in curvilinear motions? Illustrate by figure 8. How far would a cannon ball proceed when shot from the top of a high mountain if it were not for the resistance of the air? With how much greater velocity must the ball be fired to make it go quite round the earth ? In what time would it perform the whole revolution? By what *forces does the moon* revolve about the earth?

* *1 hour*, 23 minutes, and 23 seconds.

which it received when launched into space by the hand of its Creator; and were any of the heavenly bodies to explode, we may conceive that the fragments would proceed in a rectilinear direction, until approaching, severally, within the sphere of influence of some large body, whose attraction would combine with their projectile force, they would forever afterwards continue to revolve around that body, as the satellites revolve around the primary planets.

70. The attraction of gravitation is manifested by comparatively small masses of matter. The effect of a high mountain is perceptible upon a plumb line, causing it to deviate sensibly from a perpendicular, so that the same star near the zenith would change its apparent place when viewed on opposite sides of the mountain.

CHAPTER V.

OF COMPOSITION AND RESOLUTION OF MOTION.

71. SIMPLE motion is that which arises from the action of a *single* force; *compound* motion is that which is produced by several forces acting in different directions. Strictly speaking, we have no example of a simple motion, since in the absolute motion of all bodies, their own proper motion is combined with that of the earth in its diurnal and annual revolutions, and we know not with how many others. In an enlarged sense therefore all motions are compound. But in the foregoing distinctions we have reference only to relative motions, as those which take place among bodies on the earth.

72. When a body is acted upon at the same time, by two or more forces, whose directions are not in the same straight line, it is evident that it will deviate from the course in which it would have moved by the single action of either of those forces, and will proceed in some intermediate direction. Let us first consider the case of a body acted upon by *two* forces.

If I place a small ball at one of the corners of the table, and give it a snap with my thumb and finger, in a direction parallel to one edge of the table, it will of course move along that edge; or if I give the impulse with the thumb and finger of the

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Is the attraction of gravitation manifested by comparatively small masses of matter, such as a high mountain?

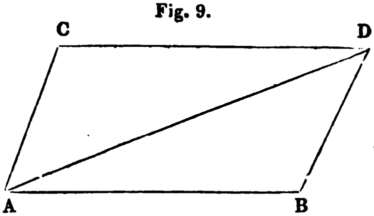
Define simple motion. Are simple motions often observed? Describe *the motion of* a ball across the table, first under one, and then under two *impulses.*

other hand, in the direction of the edge which is at right angles to the former, the ball will move along this edge; but if I give both these impulses at the same moment, the ball will move diagonally across the table from corner to corner. If the force applied to each be accurately proportioned to the length of the corresponding side of the table, (as it may be by means of springs fixed to the corner of the table,) the ball will reach the opposite corner in the *same time*, as it would have taken it to describe either side separately. This fact is generalized in the following fundamental proposition.

73. *Two impulses, which, when communicated separately to a body, would make it describe the adjacent sides of a parallelogram in a given time, will, when they are communicated at the same instant, cause it to describe the diagonal in the same time; and the motion in the diagonal will be uniform.*

This principle is called the *parallelogram of forces*.

Fig. 9.



Suppose a body, placed at A (Fig. 9.), to be acted upon by two forces, one of which would cause it to move uniformly over the line AB, and the other over the line AC in the same time; then if both forces act at the same instant upon the body, it will by their joint action move uniformly over the diagonal AD, in the same time it would have taken to describe AB or AC by the forces acting separately. By the second law of motion, every force applied to a body produces the same change of motion as though it were the only force applied. Consequently the force applied in the direction of AC, will carry a body just as far towards the line CD as though the force which acts in the direction AB were not applied. In the same manner, by the other force it will be carried just as far towards BD as though there were no other force acting upon it. Hence, the body will be found both in the lines CD and DB, when acted upon by the two forces conjointly, in the same time, that it would reach those lines res-

State the fundamental proposition respecting the composition of motion. Explain the foregoing proposition by figure 9. What is this principle called? When a body would describe two sides of a triangle under two forces acting separately, what line will it describe under two forces acting simultaneously?

pectively if acted on by each force separately. Being therefore at the end of this time in both the lines, it must be at their intersection, that is, at the point D.

74. Since AB is equal to CD and parallel to it, the two forces may be considered as acting in the direction of the two sides AC and CD of the triangle ACD; and hence *when a body would describe the two sides of a triangle by two forces acting separately, it will in the same time, describe the third side by the two forces acting jointly.*

The motion which is produced by the action of two or more forces is called the *resultant.* Thus the diagonal AD, represents the resultant of the two forces represented by AB and CD.

75. We daily observe examples strikingly illustrative of the principle just explained. In crossing a river, the boatman heads up the stream, and so combines the direction of the boat with that of the current, as to move directly across in a line which is the diagonal between the two directions; or he describes the third side of a triangle by the action of two forces which would severally carry him over the other two sides. Rowing, swimming, and flying are severally instances of motion in the diagonal between two forces. In feats of horsemanship, when the rider leaps up from the saddle, we are surprised not to see the horse pass from under him; but he retains the motion he has in common with the horse, and does not in fact ascend perpendicularly, but obliquely, rising in one diagonal and falling in another. Two men in a boat under rapid sail sitting on opposite sides and tossing the ball from one to the other, catch the ball in the same manner as though they were at rest. While, indeed, the ball is crossing the boat, the opposite man advances; but the ball also participating in the same common motion of the boat, advances mean-while in the same manner, and in reaching the other side, actually moves diagonally, with respect to the surrounding space, though with respect to the boat its motion is directly across. A body let fall from the top of a mast, when the ship is under sail, falls along down the mast and strikes at its foot in the same manner as though the ship were at rest, partaking of the common motion of the ship, and therefore describing a diagonal between this forward direction and that of gravity.

Define the term *resultant.* Examples, in crossing a river, in rowing, *swimming,* flying; in feats of horse-manship; in tossing a ball in a boat; *in a body let fall from* the top of a mast.

Fig. 10.

The *bow* and *arrow* affords an example of a body moving in the diagonal of a parallelogram under the action of two forces. Let CED (Fig. 10.) be a bow, which is stretched by the string CGD, the arrow being applied at the middle point G. Then, as the tendency of the bow to spring back is the same on each side, consequently the forces acting in the direction of GC and GD are equal. Let them be represented by Gn and Gm, and complete the parallelogram Gn K m; then GK will be the resultant and will represent the actual force by which the arrow is propelled. GK is evidently greater the more the bow is bent, which accords with experience.

Fig. 11.

In the *flight of a bird* we recognize the same principle. The bird strikes the air in the directions AD and BD, (Fig. 11.) and the reaction of the air strikes the wings in the direction DA and DB. Taking DE and DF to represent these two equal forces and completing the parallelogram, DG represents the continued effect of both, or that force under which the bird moves. It will be seen that the diagonal DG is greater as the angle at D is more acute, and consequently that the effect of the blows is greatest when they are most direct, that is, most nearly parallel to the

How do the bow and arrow exemplify the parallelogram of forces? Illustrate by figure 10. How is the resultant increased or diminished? How does the flight of a bird exhibit the same principle? In what manner must the blow be given to produce the greatest effect.

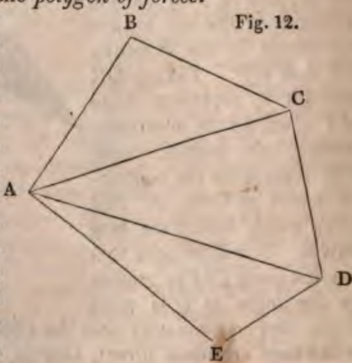
path in which the bird is flying. The force of the blows, therefore, is greatest at first, and decreases as the wing approaches the body. If the wing were of the same shape on both sides, before and behind, and if it returned in the same line, then it would lose as much in one direction as it gained in the other, and the bird would remain at rest. But the wing opens to give the blow, and then closes up and returns on its edge. Steamboats have sometimes been constructed with paddles, instead of wheels, which like the wings of a bird presented their broad side to the water in giving the blow, but returned on their edge. A skilful rower manages his oar on the same principle.

It is also evident from the figure, that if the force D F were suspended, DE would turn the bird round in the direction ABD. We here see the manner in which birds turn themselves or change their course of direction; and a steamboat, in a similar manner, turns about or changes her course by either suffering one wheel to remain at rest while the other continues acting, or by rendering the velocity of the two wheels unequal.

76. *If a body be impelled by any number of forces which, acting separately, would, in a given time, make it describe all the sides of a polygon, except the last side, when all these forces act at the same instant, the body will be made to describe the remaining side in the same time.*

This principle is called the *polygon of forces.*

Fig. 12.



Thus in Fig. 12, a body placed at A, and acted on by two forces represented in quantity and direction by AB and BC, would describe the side AC. Therefore, AC may be taken as the *equivalent* of those two forces, or as the representative of a force equal to them both, and producing precisely the same effects as they would do. For the same reason, the two

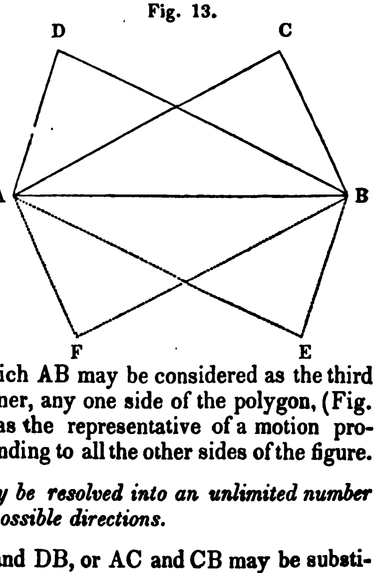
Why is not the motion gained by the blow lost while the wing returns? Explain the principle on which a bird turns or changes her direction—also a steamboat. State the proposition respecting the *polygon of forces*. *Illustrate by figure 12.*

forces AC and CD would cause the body to describe AD; and AD, therefore, represents a force equivalent to the three forces AB, BC, CD, and may be substituted for them; and, in like manner, AE may be substituted for AD and DE. Therefore under the action of the several forces AB, BC, CD, and DE, the body would describe the last side AE.

77. If the number of forces were equal, in quantity and direction, to *all* the sides of the polygon, then *the body would remain at rest* under their joint action. For the forces acting in the direction of AE, would in this case be exactly balanced by those acting in the direction of EA.

Thus AC would be the resultant of AB and BC; AD that of AB, BC, and CD; and AE that of AB, BC, CD and DE; consequently the forces represented by these four lines, if acting together, would unitedly produce a force equal to AE, and would therefore be balanced by a single force acting in the direction EA.

Fig. 13.



78. A given motion may be considered as caused by two, three, or any number of forces, as will be evident from the following figure. AB will represent a motion resulting either from the combined action of forces represented in quantity and direction, by AD and DB, or from AC and CB, or from the sides of various other triangles of which AB may be considered as the third side. In the same manner, any one side of the polygon, (Fig. 12.) may be considered as the representative of a motion produced by forces corresponding to all the other sides of the figure.

79. *A given force may be resolved into an unlimited number of others, acting in all possible directions.*

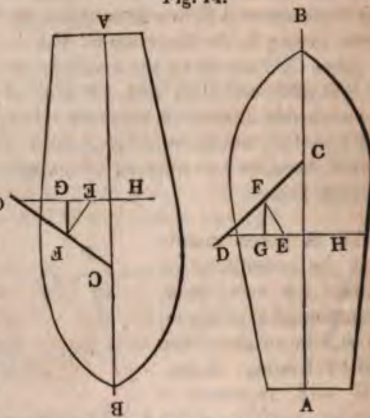
Thus (Fig. 13.) AD and DB, or AC and CB may be substituted for AB, representing forces which are equivalent to that represented by AB; and any force represented by one side of

How may a given motion be considered as caused? Illustrate by figure 13. How may any one side of a polygon be considered as produced?

the polygon (Fig. 12.) may be resolved into forces corresponding to all the other sides, the united effect of which is only equal to that of this side.

The sailing of a ship affords an instructive illustration of the principles of the composition and resolution of motion. To one unacquainted with these principles, it is apt to appear mysterious that a ship is able to sail with a wind partly ahead, and still more that two ships are able to sail in exactly opposite directions by the same wind. Let us see how this takes place.

Fig. 14.



Let AB (Fig. 14.) represent the keel of a ship, and CD the sail; and let the wind come in from the side, in the direction of HD. Let DE represent the whole force of the wind, and resolve it into two forces, viz. into EF perpendicular, and FD parallel to the sail DC. Then it is manifest that EF alone represents the effective force of the wind upon the sail. But EF is not wholly employed in urging the ship forward, since it is oblique to her course; therefore, again resolve EF into FG parallel with the course and GE at right angles with it. The force represented by GE is lost by the lateral resistance of the water, or is counteracted by the helm, while FG is employed in propelling the ship on her way.

By inspecting Fig. 14. it will readily be seen that another ship may sail in the opposite direction by the same wind; only the sail is raised on the left side when the ship is heading one way, and on the right side when it is heading the other way. When the wind strikes the sail at right angles, only one resolution is necessary; for if FE represents the whole force of the wind, FG will represent the force which propels the ship forward, while GE will represent the part which is lost by the lateral resistance of the water.

Into what forces may any given force be resolved? Illustrate by figure *13. How are the composition and resolution of motion exemplified in the sailing of a ship?* Illustrate by figure 14. Show how two ships may sail *in opposite directions* by the same wind.

80. Since, resolving the force of the wind after the foregoing manner, the effective part of the force, viz. FG, will not wholly disappear until the wind is directly ahead, it might seem possible to sail much nearer the wind than is found to be actually practicable. But though on account of the peculiar shape of vessels, the forward resistance is much less than the lateral, yet it is *something*, and therefore requires more or less of the force that acts parallel to the keel to overcome it.

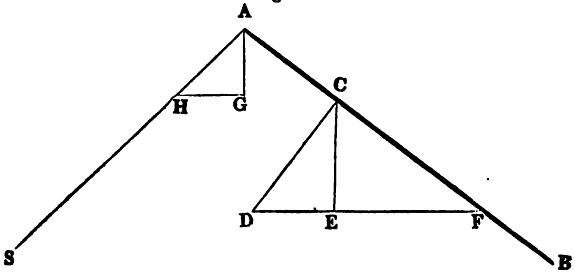
81. *A body acted upon at the same time by three forces, represented in quantity and direction by the three sides of a triangle taken in order, (or by lines parallel to these) will remain at rest.*

This principle is call the *triangle of forces.*

Since AD (Fig. 9.) represents a force which is equivalent to those corresponding to the two sides AC, CD, if upon a body placed at A, two such forces were to act while a third force corresponding to the side DA were to act upon it in the direction DA, the body being acted upon by two opposite and equal forces would remain at rest.*

82. A kite at rest in the air is commonly mentioned as an example of this, the three forces being, the direction of the wind, the weight of the kite, and the action of the string. Let AB be a kite, held by the string AS. Let DF represent the

Fig. 15.



force of the wind blowing horizontally, and resolve it into two forces, viz. DC perpendicular, and CF parallel to the kite.

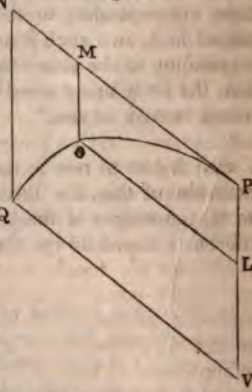
Why cannot a ship sail closer to the wind than a certain angle? State the proposition respecting the triangle of forces. Illustrate by figure 9. Example, in a kite at rest. Illustrate by figure 15.

* The three *forces are properly* represented by AC and AB acting against DA; but *CD is parallel and equal to AB, and* may therefore be substituted for it.

Then DC will be the only effective part of the wind, since that part which acts parallel to the kite, can have no influence on its motions. Again, resolve CD into two forces, namely, CE perpendicular and DE parallel to the horizon. Then CE will represent the upward force of the wind, and DE its force in a horizontal direction. Now when the string AS makes such an angle with the kite that its downward force AG, added to the weight of the kite, shall equal CE, and its horizontal force HG shall equal DE, the kite will be at rest.

83. *When two motions which are not in the same straight line are combined, one of which is uniform and the other accelerated, the moving body describes a curve.*

Fig. 16.



Thus, (Fig. 16.) when a body is thrown obliquely upwards in the direction of PN, the force of gravity will draw it continually away from that line towards the earth; and as gravity is a force which increases the motion of a falling body every instant, the body will at first recede slowly from the line PN, but more and more rapidly as it advances, describing a curve whose deviation from the line of projection continually increases, as POQ. Now, the spaces PM and PN, representing the uniform motion in the line of projection, are to one another as the squares of the spaces MO and NQ which, being equal to PL and PV, represent the descent towards the earth. But a curve described between two forces bearing this relation to each other, is known to be the curve called a *parabola*, being one of the curves which result from the sections of a cone. The parabola, therefore, is the curve belonging to all bodies projected from the earth into the atmosphere, as is seen when a stone is thrown upwards, or a fluid spouts obliquely. Forces differently proportioned to each other, describe different curves, as circles, ellipses, &c. Thus, the planets revolve round the sun in ellipses, between the force of projection and that of attraction towards the central luminary.

When do two combined motions describe a curve? Illustrate by figure 16. *What curve is described under the united forces of projection and gravity?* Under what two forces do the planets revolve about the sun?

CHAPTER VI.

OF THE CENTER OF GRAVITY.

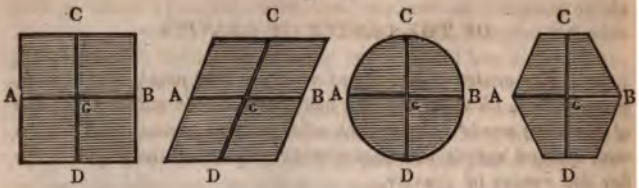
84. *The center of gravity of a body is that point, about which, if supported, all the parts of a body (acted upon only by the force of gravity) would balance each other in any position.* Thus, a staff poised across the finger, rests only when the finger is under the center of gravity.

The principles which have been discovered respecting the composition and resolution of forces, and respecting the center of gravity, have alike contributed greatly to simplify the doctrines of Mechanics. It is characteristic of a great and penetrating mind, to devise means of divesting intricate subjects of their complexity, and thus to bring easily within the grasp of the mind, subjects otherwise too much involved to be within its comprehension. By the rule of simple multiplication, we easily multiply any number by one thousand: indeed, it is nothing more than to annex three cyphers to the number itself; but how tedious would be this process, were the rule of multiplication undiscovered, and we were unacquainted with any other method of arriving at the result, except to add the given number to itself one thousand times. In like manner, by means of the rules for the composition of motion, we are enabled to reduce a thousand different motions to one; and by the doctrine of the center of gravity we are taught how we may make a force, situated at one single point, equivalent to an infinite number of forces, situated in as many different points; and, instead of pursuing the endless diversities of motion to which the different parts of a complicated system of bodies may be subject, we are taught how to follow merely the motions of a single individual point.

85. *In regular plane figures, such as squares, parallelograms, circles, &c. the center of gravity is the same with the center of the figure.* Lines drawn in the following figures bisecting the opposite sides, also bisect each other in the center of the figure, and divide the whole figure into four equal parts. When the figure rests on G, every two of these opposite parts act against each other, and being equal, exactly balance one another. The same is true of such regular solid figures as a cube, a sphere, a cylinder, &c.

Define the *center of gravity.* Give an example—of what use are the doctrines of the composition and resolution of forces, and of the center of gravity? Illustrate by a case of multiplication. Where is the center of gravity in *regular plane figures?*

Fig. 17.



86. To find the center of gravity *by experiment*, several different methods present themselves. We will first suppose the body to be in the shape of a piece of board, of uniform thickness. Suspend it by one corner, and from the same corner let fall a plumb line, and mark its line of direction on the surface of the board. Suspend the board from any other point, and mark the line of direction of the plumb line as before, and the point where these lines intersect each other, must obviously be the center of gravity, since that center is in both of the lines.

87. But when the body is not of uniform thickness, but is any irregular solid, suspend the body by a thread, and let a small hole be bored through it, in the exact direction of the thread, so that if the thread were continued below the point where it is attached to the body, it would pass through this hole. The body being successively suspended by several different points in its surface, let as many small holes be bored through it in the same manner. If the body be then cut through, so as to discover the directions which the several holes have taken, they will be all found to cross each other at one point within the body. Or the same fact may be discovered thus: a wire which nearly fills the holes being passed through any one of them, it will be found to intercept the passage of a similar wire through any other.

88. A convenient method of finding the center of gravity of a body is, *to balance it in different positions across a thin edge*, as the edge of a knife or a prism. The same thing may be effected, when the shape of the body will admit of it, by laying it on the edge of a table, and letting so much of it project over the edge, that the slightest disturbance will cause it to fall. The center of gravity is the point in which the several lines marked on the body, where the edge cuts it, intersect one another. From some or all of the foregoing trials, the center of gravity of

How can we find the center of gravity of a board, or any irregular solid? How do we find the center of gravity of an irregular solid? Ditto by means of a sharp edge, as a prism on the edge of the table?

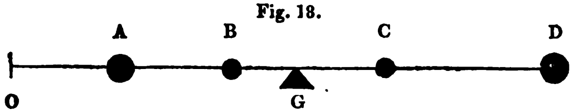
bodies may be nearly ascertained; but in order to find it with absolute exactness, we are frequently obliged to resort to intricate mathematical processes.

By whatever method the center of gravity of a body has been ascertained, we shall find that when that is supported, the body will remain at rest in every position. Thus a globe will stand securely on a very small perpendicular support, since that support will necessarily be under the center of gravity; a lever, as the beam of a balance, poised on its center of gravity, will be at rest in every position it takes while turning round the fulcrum, and however irregular the body may be, it will, when balanced on its center of gravity, obstinately maintain its position.

89. We may find the distance of the common center of gravity of any number of bodies from a given point, upon the following principles.

First, suppose the bodies have their centers of gravity in the same right line, as in figure 18, then the distance of the com-

Fig. 18.



mon center of gravity of all the bodies from the point O, will be found *by multiplying each body into its distance from that point, and dividing by the sum of the bodies.* Indeed, it is not essential that the matter in question should even reside in one and the same right line, for this principle holds good for any number of separate bodies. In figure 18, A,B,C,D, are bodies of different weights connected together by a wire which is balanced on the center of gravity G. Now we may find the distance of G from any point O in the same line, by multiplying A into AO, B, into BO, C into CO, and D into DO, and dividing the sum of these products by the sum of the bodies A,B,C and D.

90. Secondly, suppose that the bodies are not in the same right line, but are situated like a number of balls of different weights hanging at different distances from the ceiling of a room.

Why does a globe stand firm on a narrow support? Case of a lever having the center of gravity at the fulcrum. How may we find the distance of the common center of gravity of any number of bodies from a given point? Example, in the distance of the center of gravity of any number of bodies from the wall of a room.

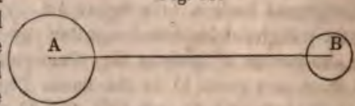
Thus, we may find the distances of their common center of gravity from the perpendicular wall of a room, *by multiplying each body into its distance from the wall, and dividing the sum of the products by the sum of the bodies.*

91. *When a body is supported by a prop placed under its center of gravity, the pressure will be the same, whether the whole quantity of matter is uniformly diffused through the space occupied by the body, or whether it is all concentrated in the center of gravity.*

In consequence of this law of the center of gravity, the reasonings on mechanical subjects are often greatly simplified. Thus, instead of estimating the pressure and other mechanical effects of a large body like the earth by considering the united effects of all its separate parts, we may often arrive at a far more simple conclusion by considering all the matter of the earth as residing in the center of gravity, and reasoning respecting it accordingly. *When bodies that compose a system are in motion, their common center of gravity will move in the same manner as if a body equal to the sum of the bodies were placed in that point, and the same forces act on it as acted on the bodies separately.*

92. *Two weights or pressures acting at the extremities of an inflexible rod void of gravity, will be in equilibrium about a given point, when their distances from that point are to each other inversely as those weights or pressures.*

Fig. 19.



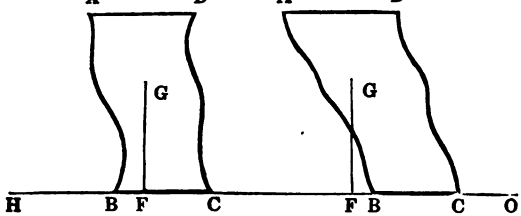
Thus, (Fig. 19.) if a weight of one pound, and another of ten pounds, are connected by a wire, and balanced by laying the wire across a thin edge, it will be found that the smaller weight is ten times as far from the support, or *fulcrum*, as the larger weight is.

93. *Whatever be the form or dimensions of a body upon a plane parallel to the horizon, it will remain at rest, if the line drawn from its center of gravity perpendicular to the horizon falls within its base.*

What is the effect of supposing the matter all concentrated in the center of gravity? When a system of bodies are in motion, how does their common center of gravity move? How must two weights acting at the ends of an inflexible rod be situated with respect to the center of gravity, in order to be in equilibrium?

For let ABCD (Fig. 20.) represent the section of a body, passing through its center of gravity G, and draw GF perpendicular to HO the plane upon which it stands; then, since the tendency of the body to descend is the same as if its whole

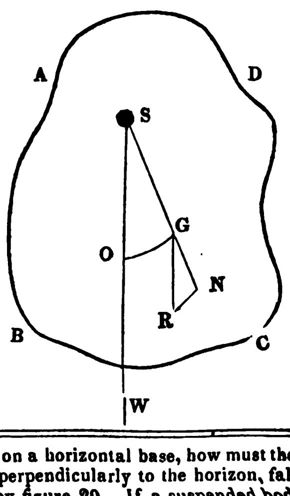
Fig. 20.



weight were concentrated in G, it will *rest* or *fall* according as G is *supported* or *not*; i. e. according as F falls *within* or *without* the base BC; moreover, the *stability* of the body will depend upon the distance at which the point F falls *within* the base.

94. *If a body be suspended from any point, it will not rest till the line which joins the center of gravity and point of suspension is perpendicular to the horizon.*

Fig. 21.



For let ABCD (Fig. 21.) represent the section of a body as before, G its center of gravity, S the point of suspension; join SG, and draw SOW perpendicular to the horizon; produce SG to N, and draw GR parallel to SW; then, since the weight of the body may be considered as collected in G, its *tendency to motion* will be along the line GR. Let GR therefore represent this tendency, which resolve into GN in the direction SG, and RN, perpendicular to it; the part GN is counteracted by the reaction from the point of suspension S, and NR is employed in producing

In order that a body may stand firm on a horizontal base, how must the line drawn from the center of gravity perpendicularly to the horizon, fall with *respect to the base?* Illustrate by figure 20. If a suspended body *swing freely on a point, on coming to rest how is the line situated which joins the center of gravity* and point of suspension? Illustrate by figure 21.

motion in the direction of the circular arc GO; G therefore (and consequently the *body*) will not remain at rest till NR vanishes, i. e. till the angle NGR (=OSG) vanishes, or SG coincides with SO.

95. When a body is suspended from a center of motion, and revolves around it, in a circle perpendicular to the horizon, it will be at rest only *when the center of gravity is either directly below, or directly above the center of motion.* For it is only in these two cases, that the center of gravity will be in the line which is drawn through the center of motion perpendicular to the horizon. The stationary point above the center of motion is very *unstable*, since the slightest disturbing force throws the body out of the line of direction, when, by the force of gravity, it immediately descends to the lowest point it can reach, and vibrates about that point until it finally settles itself with the center of gravity immediately under the point of suspension; and whenever it is thrown out of this position, the same vibrations are renewed until it resumes it. When, therefore the center of gravity is at the lowest point it is capable of reaching, the equilibrium is *stable*, since the body obstinately maintains that position. On this principle, gates which have their center of gravity raised as they are opened, shut spontaneously.

96. The stability of a body not only requires that the center of gravity should be low, but that *the line of direction* (or, the line which is drawn through the center of gravity perpendicular to the horizon) *should fall within the base.* The farther it falls from the extremity of the base, the more stable is the position. Hence the stability of a pyramid when standing on its broad base, and its instability when inverted. For the same reason, all broad vessels, as steam boats, are difficult to upset, while vehicles with narrow bases are easily overturned. When a load is so situated as to raise the center of gravity, it increases the liability to upset, because it increases the facility with which the line of direction is thrown without the base. Thus carts loaded with hay, or bales of cotton, are very liable to be overturned. The same is true of stages carrying passengers or baggage on the top. On the other hand, a

When a body swings around a center of motion in a circle which is perpendicular to the horizon, at what two points will it remain at rest? Which of these points is stable, and which unstable? Exemplified in gates. Cause of the stability of a pyramid? Examples, of structures rendered stable on the same principle. What is the effect on the stability of a body produced by raising the center of gravity? Examples, in loads of hay, stages, &c.

large ship well supplied with ballast is capsized with great difficulty, since the center of gravity of all parts of the ship is so low, as to render it difficult to throw the line of direction without the base. Yet if the center of gravity is very low, a ship will rock excessively in a rough sea, since the upper parts near the deck, move over a greater space in proportion as their distance from the center of gravity is greater.

97. There are many remarkable structures which *lean* or incline a little; but so long as the line of direction falls within the base, and the parts of the mass have sufficient tenacity among themselves to hold together, the structure will stand. The famous Leaning Tower of Pisa, was built intentionally inclining, to frighten and surprise: with a height of one hundred and thirty feet, it overhangs its base sixteen feet. Yet since the lower parts are of greater dimensions than the upper, and the walls thicker below than above, the center of gravity is so low that the line of direction falls far enough within the base to give the whole structure sufficient stability, while its apparent tendency to fall greatly enhances the emotion of the spectator from its summit. Many ancient spires and other tall structures, are found to have lost something of their perpendicularity.

Fig. 22.

98. *Rocking stones* are rocks which are sometimes found so exactly poised upon their center of gravity, that a very small force is sufficient to put them in motion. The rocking of a balloon when it begins to ascend, affords an illustration of the tendency of bodies to vibrate around the center of gravity.

99. The *motions of animals* are regulated in conformity with the doctrines of the center of gravity. A body is seen tottering in proportion as it has great altitude and a narrow base; but it is a peculiarity in man to be able to support his figure with

Explain why a *ship rocks* when the center of gravity is very low. *What is the peculiar structure* of the Leaning Tower of Pisa. Explain *the case of rocking stones*—rocking of a balloon.

great firmness, on a very narrow base, and under constant changes of attitude. The faculty is acquired slowly, because of the difficulty. The great facility with which the young of quadrupeds walk, is ascribed to their broad supporting base. Many of our most common motions and attitudes, depend for their ease and gracefulness, upon a proper adjustment of the center of gravity. The erect posture of a man carrying a load upon his head—leaning to one side when a heavy weight is carried in the opposite hand—leaning forward when a weight is on the back—or backward when the weight is before;—

Fig. 23.

these are severally examples in point. When a man rises from his chair, he brings one foot back, and leans the body forward, in order to bring the center of gravity over the base; and without adjusting it in this manner, it is hardly possible to rise. A man standing with his heels close to a perpendicular wall, cannot bend forward sufficiently to pick up any object that lies on the ground near him, without himself falling forward.

100. The art of *rope or wire dancing*, depends in a great degree upon a skilful adjustment of the center of gravity. The rope dancer frequently carries in his hand a stick loaded with lead, which he so manages as to counterbalance the inclinations of his body which would throw the line of direction out of the base. Upon a similar principle the equestrian balances himself on one foot on a galloping horse.

101. The *vegetable creation* is subject also to these general laws of nature. Trees by the weight and height of their tops would seem peculiarly liable to fall; but their roots afford a

Explain the motions of animals in conformity with the doctrine of the center of gravity. How is the art of rope or wire dancing related to this *subject?* How is the same principle illustrated in the structure of trees *and plants?*

corresponding breadth of base, while their perpendicular trunks, and the symmetrical disposition of the branches, conspire to increase their stability.

102. The position of the center of gravity of any number of separate bodies, is never altered by the *mutual action* of those bodies on each other. If, for example, two bodies, by mutual attraction, approach each other, the center of gravity remains at rest, until finally the bodies meet in this point. If, by their mutual action, they contribute to make each other revolve in orbits, it is around their common center of gravity. Thus the earth and moon revolve around a common center of gravity, which remains fixed: the same is true of the sun and all the bodies that compose the solar system. Were the centrifugal force to be suspended, and the bodies abandoned to the mutual action of each other, they would all meet in their common center of gravity. This naturally results from the principle that the momenta on opposite sides of the center of gravity are equal, and that bodies by their mutual action produce equal momenta in each other.

103. The doctrines of the center of gravity, suggest the readiest method of solving a great number of practical problems. We annex a single example.

Suppose three persons were carrying a stick of timber, (A by himself supporting one end, and B and C by a handspike lifting together towards the other end,) and it were required to determine at what distance from the end of the stick the handspike must be placed, in order that the three persons might bear equally.—A stick of timber being a body of regular shape and uniform density, has its center of gravity coincident with the center of magnitude. We may therefore proceed on the supposition that the entire weight is collected in the center. Now in order that B and C may together lift twice as much as A, they must be twice as near the center. But the distance of A from the center is half the length of the stick; therefore the distance of the required point from the center is one fourth the length of the stick, and consequently it is one fourth the same length from the end of the stick. To test this case by experiment, we might rest one end of the stick upon a support, and ascertain, by a pair of steelyards, the weight at a distance from the other end equal to $\frac{1}{4}$ the length of the stick. It would be found equal to $\frac{2}{3}$ the weight of the whole stick.

How is the position of the center of gravity of any number of bodies affected by their mutual action?

CHAPTER VII.

OF PROJECTILES AND GUNNERY.

104. *A projectile is any body thrown into the atmosphere.* A ball fired from a cannon, a stone thrown by the hand, and an arrow shot from a bow, are severally examples of projectiles. According to article 83, projectiles rise and fall in the curve of a parabola under the combined forces of projection, which tends to carry them uniformly forward, and of gravity, which brings them with accelerated velocity towards the earth.

105. *The random of a projectile is the horizontal distance between the point from which it is thrown, and that where it falls to the earth.*

For example, when I throw a stone obliquely into the air, it rises and falls in a curve, (the parabola) and the distance from the place where I stand to the place where it falls, measured on the surface of the earth, is its random. The *random is greatest* when the angle of elevation is 45 degrees, and is the same at elevations equally distant above and below 45 degrees. It is the same, for instance, at 60 and at 30 degrees.

A projectile rises to the *greatest height* when thrown perpendicularly upwards, and it remains, in this case, longest in the air; or the *time of flight* is greatest when a body is projected directly upwards.

106. When a body is thrown horizontally from any elevation, with a velocity equal to that which it would have acquired by falling from that elevation to the earth, its random is *twice* as great as that height. Thus, if I throw a ball from a chamber window, with a velocity which it would have acquired in falling from the window to the ground, it will fall at a distance from the foot of the building equal to twice the height of the window.

107. The foregoing principles hold good only when projectiles move without resistance. But this is far from being the

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What is a *projectile?* Give examples. In what curve does a projectile rise and fall? Under the action of what forces does it move? What is the *random* of a projectile? At what angle is the random greatest? At what two angles are the randoms equal? When does a *projectile rise* to the greatest height? When is the time of flight greatest? *What is the* random of a body thrown horizontally from a chamber window? Do the theoretical principles of projectiles hold good in practice?

fact, since the resistance of the air, especially to the bodies moving swiftly through it, is very great; and hence the discordance between theory and experiment is such, that the mathematical principles of projectiles are found to be wholly inapplicable to practice.

It is ascertained, in general, that projectiles moving *slowly*, describe curves which are nearly parabolas; while such as move *swiftly* deviate very far from this curve. The parabolic figure described in the case of projectiles which move slowly, may be observed in tracing the path of a small stone thrown into the air, and more especially in the curves described by jets of water spouting upwards, as in fountains. But when the jet is more rapid, and spouts at a high angle, as forty five degrees for example, we can plainly see that the curve deviates greatly from a parabola. The remote branch of the curve is seen to be much less sloping than the rising branch; and in very great jets, which are to be seen in some great water works, the falling branch is almost perpendicular at its remote extremity; and the highest point of the curve is far from being in the middle between the spout and the place where the water falls. The unequal division of the curve by its highest point, may also be observed in the flight of an arrow or a bomb shell.

108. The following facts also shew the discordance between the parabolic theory of gunnery and experience. A cannon ball, fired in such a direction and with such a velocity, that its random or horizontal range, ought to be twenty four miles, comes to the ground short of one mile. The times of rising and falling, if that theory held good, ought to be equal; but the time of rising is greater than that of falling at great elevations, and at small elevations less than that of falling. According to the theory, the greatest random is at an angle of elevation of forty-five degrees, but in practice it is found to be much below this. The greatest random of an arrow, is when the elevation is about thirty six or thirty eight degrees.

109. This discordance between theory and practice is owing to the resistance of the air, which, when the projectile moves with great velocity, becomes enormous. Nor will it be difficult, on a little reflection, to comprehend the reason why

What curve is described by projectiles moving *slowly*? Ditto when moving *swiftly*? Examples, in a stone thrown into the air, and in spouting fluids. Discordance between theory and practice exemplified in the motion of a cannon ball. At what angle of elevation is the random of an *arrow greatest? What occasions the discordance between the theory and practice of gunnery?* In what ratio to the velocity does the *resistance of the air increase?*

this resistance should be so great. The force with which a projectile strikes the air at rest, is the same as that with which the air moving with equal velocity would strike the body at rest. This, in the case of a cannon ball, would greatly exceed the most violent hurricane. Again, as a ball moves through the air, it displaces, that is, gives motion to, great quantities of air; yet whatever motion it imparts to other bodies is extinguished in itself. The loss of motion, therefore, increases very fast with the velocity. It is said to be in general as the square of the velocity: so that a body moving through the air with ten times the velocity of another body, would encounter one hundred times as much resistance. In very swift motions, the resistance was ascertained by Robins to be even much greater than in the ratio of the square of the velocity.

110. The researches of Mr. Robins were made chiefly by the aid of an instrument of his own invention, called the *Ballistic Pendulum.* It consists of little more than a large block of wood, like a log, suspended after the manner of a pendulum. Now if a bullet be fired into the block, as the bullet will be stopped, and as it imparts to the block whatever motion it loses, consequently the momentum of the block after the stroke, is precisely that of the ball before the stroke. Hence the weight of the block and that of the ball being known, and the velocity imparted to the block being readily determined by observation, it is easy to find the velocity of the ball; for the weight of the ball is to the weight of the block, as the velocity of the block is to the velocity of the ball.

111. This simple apparatus is sufficient for ascertaining a great number of particulars relative to the art of gunnery. If the ball is fired nearly in contact with the block, we find with what velocity it leaves the gun; if at different distances from the block, we find how much the velocity is retarded by passing through the air, for those distances respectively. If, at a given distance, we vary the charge of powder, we find the respective changes which the velocity undergoes, and hence learn the ratio that ought to be observed between the powder and the ball, in order to produce the maximum effect. The effects resulting from variations in the length, shape and bore of the gun, are also ascertained with equal facility.

How is the resistance in very swift motions? Describe the *Ballistic Pendulum.* How is the velocity of a ball ascertained by it? How, by the ballistic pendulum, can we find with what velocity a ball leaves the gun? What resistance it meets with from the air?

112. The following are some of the practical results ascertained by the experiments of Mr. Robins, Count Rumford, and Dr. Hutton. A musket ball, discharged with a common charge of powder, issues from the muzzle of the piece with a velocity between 1600 and 1700 feet in a second. The utmost velocity that can be given to a cannon ball is 2000 feet per second, and this it has only at the moment of leaving the gun. In order to increase the velocity from 1600 to 2000 it requires half as much more powder, which involves a hazardous strain upon the gun, and the velocity will be reduced to 1300 before the ball has proceeded 500 yards.

113. From the foregoing considerations it is inferred, that great charges of powder are absolutely useless in the service of artillery, especially when the distance of the object is considerable, and that a velocity exceeding 1100 should not be aimed at. The maximum service charge is $\frac{1}{3}$ the weight of the ball. In close naval engagements, great velocities are injurious, for the ball may then pass through both sides of the vessel without lodging, and the number of splinters produced by a ball in rapid motion, is much less than is caused by one moving more slowly. By reducing the charge we may also reduce the size and strength of the gun; and hence guns are made of smaller dimensions now than formerly, in order to do the same execution. The velocity with which a charge of powder expands itself at first, is estimated by Hutton as high as 5000 feet per second. As it expands, this velocity is of course constantly diminishing, but will exceed that of the ball while the latter is passing through the barrel of the gun, and will act as a constantly accelerating force. Long guns, therefore, give to balls a greater velocity than short ones; but the gain secured in this way after a moderate length is so small, (there being also some disadvantages peculiar to long guns,) that cannon have of late years been much shortened. In the naval service, *carronades* have been introduced. These are a short kind of gun, with small bore, requiring for a charge of powder, only one twelfth the weight of the ball. Their weight and thickness are proportionally reduced, yet in close action they produce effects superior to those of long guns.

With a velocity of how many feet per second does a musket ball leave the gun? What is the greatest velocity that can be given to a cannon ball? How much more powder is required to increase the velocity from 1600 to 2000? What is said of great charges of powder? What is the ratio between the weight of the powder and the ball? Does a swift or slow ball damage a ship most? With what velocity does a charge of powder expand itself? Why do long guns give a greater velocity to balls than short ones? What are carronades?

114. It has been found that no difference is caused in the velocity, or range, by varying the weight of the gun, nor by the use of wads, nor by different degrees of ramming, nor by firing the charge of powder in several places at the same time; but that a very great difference in the velocity arises from a small degree in the *windage*, or the difference between the diameter of the ball and that of the gun. Indeed, with the usual established windage only, viz. about $\frac{1}{20}$ of the calibre, no less than between $\frac{1}{4}$ and $\frac{1}{3}$ of the powder escapes and is lost, and as the balls are often smaller than the regulated size, it frequently happens that half the powder is lost by unnecessary windage. To this cause also, namely, too great windage, Dr. Hutton ascribes a great part of the sideways deviation of a ball; since when, in passing through the barrel of the gun, it is knocked from side to side, it will finally take the last direction which it happened to have at the muzzle of the gun. Another cause of this deviation from the line of direction, arises from a want of perfect sphericity in the ball, by which means the two sides do not meet with equal resistance. Rifles owe their superiority over common guns, chiefly to their obviating this deviation. They have a spiral groove cut in their bore, making about a turn and a half in the whole length of the barrel. The ball, which is made to fit close to avoid too great windage, has a corresponding motion impressed on it, which it retains after it leaves the gun, continuing to revolve around the line of direction. Whatever inequalities, may exist in the ball, their effects are neutralized, by their being first on one side and then on the other of this line.

115. When a ball is projected from a piece of ordnance, at a small angle of elevation, and falls upon water, or on a plane of hard earth, its flight will not cease, but it will rise again and describe a second curve similar to the first but less; and it will continue to rebound, until the whole of its projectile velocity is destroyed. This species of firing is called *Ricochet.* It is applied with great advantage from sea coast batteries upon shipping, and in the attack of fortresses. The pieces are fired with small charges of powder and elevated only from 3 to 6

Is the shot affected by varying the weight of the gun, or by ramming? What is meant by *windage*, and what is its effect? What is the usual amount of windage? How much of the charge is lost? What are the causes of irregularity in the motion of the ball? What is the structure and principle of rifles? What happens when a cannon ball is fired at a small angle of elevation, and falls on water? What name is given to this mode of firing? Where is it applied? What does the word *Ricochet signify?*

degrees. The word signifies *duck and drake*, or rebounding; because the ball or shot thus discharged, goes bounding and rolling along, killing or destroying every thing in its way, like the bounding of a flat stone along the surface of water when thrown almost horizontally.

CHAPTER VIII.

OF MACHINERY.—THE LEVER.

116. THE organs employed in communicating motion, are tools, machines, and engines. *Tools* are the simplest instruments of art; these when complicated in their structure, become *machines;* and machines when they act with great power, take the name of *engines*. Among the ancients, machines were confined chiefly to the purposes of *architecture* and *war;* and they were moved almost exclusively by the *strength of animals*. Thus, in building one of the great Pyramids of Egypt, vast masses of stones were raised to a great height, amounting together to 10,400,000 tons. In this labor were employed 100,000 men for twenty years. The advantage which man has gained by pressing into his service the great powers of nature, instead of depending on his own feeble arm, is evinced by the fact, that by the aid of the steam engine, one man can now accomplish as much labor as 27,000 Egyptians, working at the rate at which they built the pyramids. In war also, while the use of gunpowder was unknown, engines of great power were invented for throwing stones and javelins, and for demolishing fortifications. Such were the Catapulta, the Ballista, and the Battering Ram, of the Romans. Yet it is remarkable, that during many ages, while such powerful auxiliaries were employed in architecture and in war, the ancients should have made so little use as they did of machinery in the ordinary processes of the arts. The practice of grinding corn by hand, which was chiefly performed by women, was prevalent at Rome until the time of Augustus, when we find the first mention of water mills.

The *elements of machinery* are found in what are called the *Mechanical Powers*. They are six in number, viz. the Lever,

Distinguish between tools, machines, and engines. To what purposes were machines chiefly confined among the ancients? How were they moved? Example in building the great Pyramid of Egypt. Compare *the labor of a man aided by the* steam engine with the Egyptians.

the Wheel and Axle, the Pulley, the Inclined Plane, the Screw, and the Wedge.

THE LEVER.

117. *The* LEVER *is an inflexible bar or rod, some point of which being supported, the rod itself is movable freely about that point, as a center of motion.*

This center of motion is called the FULCRUM OR PROP.

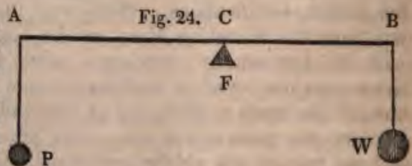
When two forces act on one another by means of any machine, *that which gives motion is called the* POWER ; *that which receives it the* WEIGHT.

A lever is *straight* when its arms (or the parts on each side of the fulcrum) are in one continued straight line ; *bent*, when the two arms are straight, but make any angle with each other at the center of motion ; and *crooked*, when one or both arms deviate from a straight line.

118. In treating of the Mechanical Powers, the first inquiry is, *what are the conditions of an equilibrium ;* that is, when do the power and weight exactly balance each other ? This point being ascertained, any addition to the power puts the weight in motion. The investigation first proceeds on the supposition that the action of the mechanical powers is not impeded by their own weight, or by friction and resistance, a suitable allowance being afterwards made for the various impediments.

119. *Two weights will balance each other upon the arms of a lever when they are to each other inversely as their respective distances from the fulcrum.*

Fig. 24.

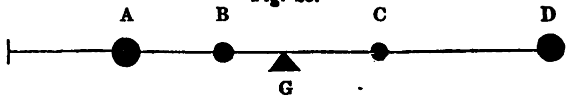


Thus in Fig. 24, if W is as much heavier than P as AC is greater than BC, the two weights will exactly balance one another. Here the product of P into AC, is equal to the product of W into BC, and in all cases where the product of the weight into its

Enumerate the Mechanical Powers. Define the lever, the fulcrum, the power, the weight. Distinguish between the straight, the bent, and the crooked lever. What is the first inquiry in treating of the mechanical powers? Do we take into the account friction, resistance of the air, &c? When will two weights balance each other on the arms of a lever? *Explain* the principle by Fig. 24.

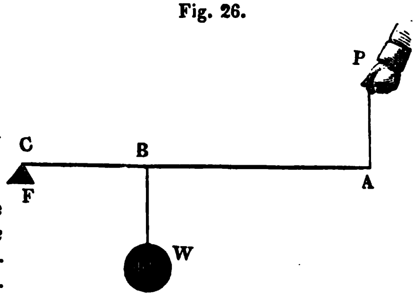
distance from the fulcrum, is equal to the product of the power into its distance, the weight and the power will be in equilibrium.

Fig. 25.



120. This is true even where there are several weights on each side as in figure 25. If the products of A and B into their respective distances from G, be equal to the similar products of C and D, the weights on the opposite sides will balance on another.

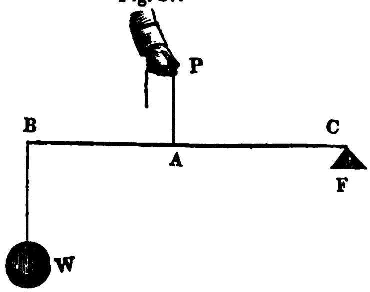
Fig. 26.



121. Levers are divided into *three different orders*, according to the position of the power and weight with respect to the fulcrum.

1. In a lever of the *first* kind, the fulcrum is between the power and the weight as in Fig.24.
2. In a lever of the *second* kind, the weight is applied between the power and the fulcrum, as in Fig. 26.

Fig. 27.



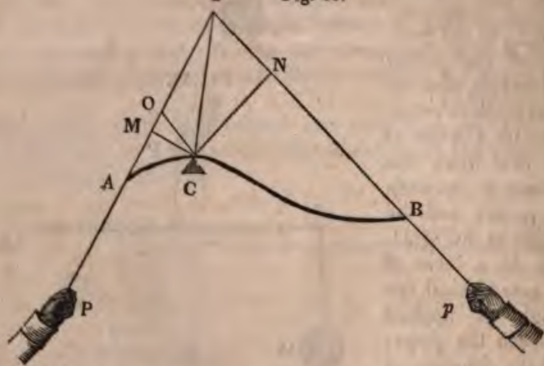
3. In a lever of the *third* kind, the power is applied between the weight and the fulcrum, as in Fig. 27.

How does the product of the power into its distance from the fulcrum compare with that of the weight into its distance? Does the same principle of equilibrium hold when there are several weights on each side? How many kinds of levers are there? How is the fulcrum situated in the first—in the second—in the third?

The same law of equilibrium (Art. 119) holds good in the three kinds of levers; and where the power is at a greater distance from the fulcrum than the weight, as in the first and second kinds, it is proportionally less than the weight, and where it is nearer the fulcrum than the weight, as in the third kind, it is proportionally greater than the weight, or acts under what is called a *mechanical disadvantage*. When a weight is sustained by two props, as when two men carry a weight suspended from a pole, one end of which rests on the shoulder of each, the part borne by each man is less as the distance of the weight from him is greater. Thus, if the pole is 10 feet long and a weight of 500 pounds is suspended 2 feet from A and 8 feet from B, then A's part will be to B's as 8 to 2, or as 4 to 1; so that A will support 400 lbs. and B 100.

122. When levers are not *straight*, but more or less crooked, a similar principle of equilibrium holds good, the distance of the weight or power from the fulcrum being estimated by the length of a perpendicular drawn from the fulcrum to the line of direction in which the power acts. Thus in figure 28, ABC is

Fig. 28.



a crooked lever in which the power and weight act in the directions of the lines BS and AS. Now the distances from the fulcrum being measured by the perpendiculars CM and CN, the general law of equilibrium holds, viz. that the power is to the

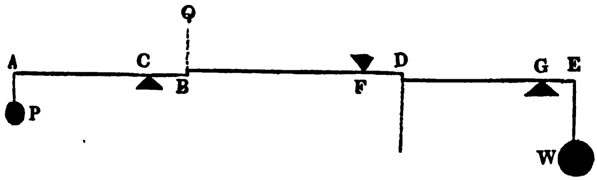
Case where the power is at a greater distance from the fulcrum than *the weight.* Case where the weight is farther off than the power. Case *of a weight on a pole* borne by two men. How is the same principle of *equilibrium applied* when the lever is not straight?

weight, as the distance of the weight from the fulcrum is to the distance of the power from the fulcrum.

123. A *compound lever* consists of several simple levers combined together.

In a compound lever, the power and the weight balance each other, when the product of the power multiplied into all the arms on the side next to it, is equal to the product of the weight into all the arms next to the weight.

Fig. 29.



Thus, in figure 29, the product of $P \times AC \times BF \times DG = W \times GE \times FD \times CB$. Suppose, for example, the longer arms of the lever are severally twice the length of the shorter, and that the weight to be raised equals 400 pounds; what power must we apply? $1 \times 1 \times 1 \times 400 = 2 \times 2 \times 2 \times 50$. Hence, 50 lbs. applied at P would balance 400 lbs. at W.

124. *Examples.*

1. Upon the extremities of a straight lever, are hung two weights, A and B, the former weighing 15 and the latter 60 pounds; how much farther is A from the fulcrum than B? By figure 24, AC : CB : : 60 : 15; but 60 : 15 : : 4 : 1; therefore, the smaller weight is four times as far from the fulcrum as the larger.

2. One end of a lever is 44 feet, and the other 5 feet; what power must I apply to the longer end to balance a weight at the shorter end of 500 lbs.?

$$44 : 5 : : 500 : \frac{5 \times 500}{44} = 56 \text{ lbs. } 13\tfrac{1}{11} \text{ oz. Ans.}$$

3. In a compound lever, (Fig. 29,) the lengths of the longer arms are 5, 10, 16 feet, respectively, and of the shorter 1, 2, 3

What is a *compound lever?* When do the power and weight balance *each other?*

feet; what power, applied to the longer side, will be required to balance a weight of 100 pounds?

$5\times10\times16 : 1\times2\times3 :: 100 : \frac{3}{4}$ lb. Ans.

4. Wishing to lift from its bed a rock weighing 1000 lbs., I take a handspike 6 feet long, and applying the shorter end to the rock, rest it on a fulcrum at the distance of $1\frac{1}{2}$ feet from the rock; how much force must I exert at the end of the longer arm to raise the rock? Ans. $333\frac{1}{3}$ lbs.*

5. A lever of the second order is 20 feet long: at what distance from the fulcrum must a weight of 112 lbs be placed, so that it may be supported by a power able to sustain 50 lbs. acting at the extremity of the lever?

Ans. 8 feet and $11\frac{1}{7}$ inches.

6. In a compound lever, the three shorter arms are, respectively, 1, 2, 4 feet; the three longer arms 9, 11, 12; the power applied at the end of the longer arm is 3 pounds: what weight will it raise? Ans. $445\frac{1}{2}$ lbs.

125. The principle of the lever has a most extensive application in the arts, and the forms under which it occurs are very various. We may contemplate it as having equal or unequal arms.

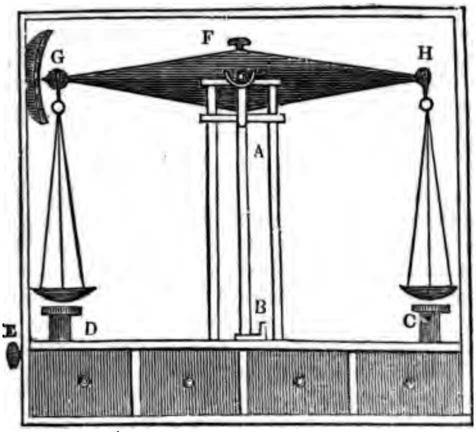
The *balance* affords the most common example of a lever with equal arms. The necessity of arriving at the weight of bodies with the greatest degree of accuracy in pecuniary transactions, and more especially in delicate scientific researches, as those of chemical analysis, has induced men of science, and artists, to bestow great and united attention upon the construction of this instrument, until they have brought it to an astonishing degree of perfection.

126. The principal parts of the balance are the beam GH, (Fig. 30,) the points of suspension G and H, and the fulcrum F. In order to construct a perfect balance, the most important particulars to be attended to, are the length of the arms, that is, of the beam; the situation of the center of gravity of the whole instrument, with respect to the fulcrum or center of motion; and the position of the point of suspension.

Balance—what sort of a lever is it? Why has so much pains been taken to make it accurate? Describe it from the figure. What particulars are especially to be attended to in its construction?

* This force would just *balance* the weight; any additional force would *raise* it.

Fig. 30.



(1.) The sensibility of the balance is increased by increasing the *lengths of the arms;* but unless the arms, when long, are at the same time of considerable weight, they will not have the requisite strength, but will be liable to bend; and an increase of weight, adds to the amount of friction on the center of motion. It is not common, therefore, to make the arms of a very delicate balance more than nine inches in length; and, for the purpose of uniting lightness with strength, the beam is composed of two hollow cones placed base to base, as in Fig. 30.

(2.) The *center of gravity* of the instrument, must be a little below the center of motion. For if the beam is balanced on its center of gravity, it will remain at rest in every position, whereas it must be at rest, only when in a horizontal position. If the center of gravity is above the center of motion, the position is too unstable, and on the least disturbance of the equilibrium, the beam will be liable to upset. Finally, if the center of gravity is too far below the center of motion, the equilibrium will be too stable. Hence, in very delicate balances, the center of motion is placed a little above the center of gravity.

(3.) The *points of suspension* must be in the same right line with the center of motion. For since when weights are added

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How is the sensibility of the balance affected by increasing the lengths of the arms? How long are the arms of the most delicate balances? What is the situation of the center of gravity? Why is not the beam balanced on its center of gravity? What is the effect of placing the center of gravity *above the center* of motion? or of placing it too low? *How are the points of suspension situated?*

to the scales, the effect is the same as though they were concentrated in the points of suspension; and were those points above the center of motion, the center of gravity would be liable to be shifted above the centre of motion, when the beam would upset; and if the same points were below the center of motion, unless the weights added were large, the center of gravity would be too low, and the equilibrium too stable.

127. In order to prevent friction as much as possible, the *fulcrum* is made of hardened steel, and shaped into a triangular prism, or knife edge, smoothly rounded, and turning on a plane of agate or steel, or some other very hard and polished substance.

It is only by a nice attention to all these particulars that artists have been able to give to the balance so great a sensibility. Some balances have been made to turn with the 1000th part of a grain. By loading the beam the sensibility of the instrument is diminished; (Art. 126.) it is customary, therefore to estimate its power by finding what part of the weight with which it is loaded it takes to turn it. Thus, if when loaded with 7000 grains, it will turn with 1 grain, its power is $\frac{1}{7000}$. A balance constructed by Ramsden, a celebrated English artist, for the Royal Society, turned with the *ten millionth* part of the weight. Delicate balances are usually covered with a glass case to prevent agitation from the air, and to secure them from injury. Figure 30, represents an instrument of this kind made for the Royal Institution of Great Britain.

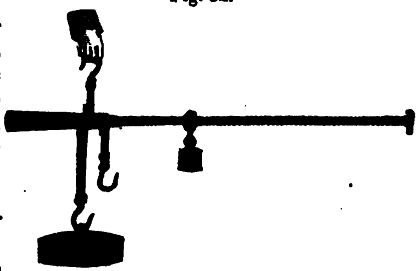
128. The *bent lever balance* is represented in figure 31. The weight C acts as though it were concentrated in the point D, and the weight in the scale acts at K; hence an equilibrium will take place, when the article weighed has to C the same ratio as DB has to BK. Now every increase of weight added to the scales causes C to rise on the arc F G, and D to recede from B. Hence the different positions of C, according as different weights are added to the scale, may be easily determined, and the corresponding numbers marked on the scale F G.

Fig. 31.

Of what is the fulcrum made? Give an example of the extreme delicacy of some balances. Describe the bent lever balance.

129. It is essential to an accurate balance, that the two arms should be precisely equal in length. The *false balance*, which is sometimes used with a design to defraud, has its arms unequal. The dealer turns such an instrument to his account both in buying and selling. In buying, he puts his weights on the longer side, for then it takes more than an equivalent to balance them; and, in selling, he puts his weights on the shorter side, because less than an equivalent will produce an equilibrium. The fraud may be detected by making the weights and the merchandize change places. The true weight may be determined from such a balance, by putting the article whose weight is to be determined, into one scale, and counterpoising it with sand, shot, or any convenient substance, in the other scale, and then, removing the article, and finding the exact weight of the counterpoise. It is evident that the weight of the merchandize will be the same as that of the weights employed to balance its counterpoise.

Fig. 32.



130. The *steelyard* is a lever having unequal arms, in which the same body is made to indicate different weights, by placing it at different distances from the fulcrum. A pair of steelyards has usually two graduated sides for determining smaller or greater weights. It will be seen that on the greater side, the weight is placed nearer the fulcrum. Consequently, the weight indicated by the counterpoise, when at a given distance from the fulcrum, will be proportionally greater. This instrument is very convenient because it requires but one weight. The pressure on the fulcrum, excepting that of the apparatus itself, is only that of the article weighed, whereas in the balance, the fulcrum sustains a double weight. But the balance is susceptible of more sensibility than the steelyard, because the subdivisions of its

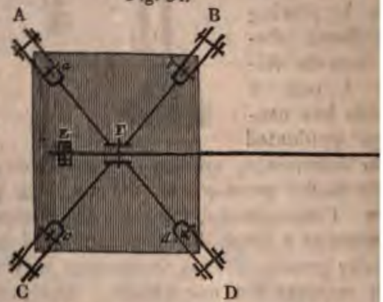
How are the arms of the *false balance?* How does the dealer use it so as to defraud? How may the fraud be detected? The steelyard defined—point out the difference between the greater and the lesser side, and show upon *what principle they* respectively act. What advantages *has the steelyard over the* balance? What advantage has the balance *over the steelyard?*

weights can be effected with a greater degree of pre
than the subdivision of the arm of a steelyard.

131. The *spring steelyard* is a very convenient instrument for weighing where the subdivisions of weights are large. It depends on the elasticity of a spiral steel spring, to compress or extend which requires a force proportioned to the degree of compression or extension. The manner of applying it will be easily understood from the representation in figure 33. After continued use, especially when loaded with heavy weights, the elasticity of the spring is liable to be impaired, and the accuracy of the instrument diminished. When made, however, in the best manner, spring steelyards retain their accuracy for a long time.

132. The steelyards or balance used for estimating very heavy weights, as loaded carts, depends upon the principle of the compound lever. The several leve usually placed beneath a platform, which rests on pivot nected with the shorter arms, while the counterpoise i nected with the extremity of the longer arms. In figu is represented a weighingmachine employed in England, for estimating loads that are transported on turnpike roads. It consists of a platform* resting on four levers of the second kind, the weight being between the fulcrum and the power. The fulcrums are A, B, C, D, and th form, and consequently the weight rests on the points *a*, The pressures on these four points are transmitted to th of the levers at F, and since the ends of the levers all a common support at F, this point sustains a pressure ec

Fig. 34.



Describe the spring steelyard. On what principle does it d
Describe the weighing machine represented in figure 34.

* *The figure* represents the under side of the platform.

the combined forces exerted at the ends of the four levers. This force again is increased by the lever E G, and finally transmitted to G, to which the weighing part of the apparatus is attached. Suppose AF to be ten times the length of A*a*, then 10 pounds at F would balance 100 pounds at *a*, and if the arm EG is ten times the length of EF, then ten pounds at G will balance 100 pounds at F. Let us then apply ten pounds at G; this pressing upon F with the force of 100 lbs., will press upon *a* with the force of 1000 pounds. This would be the case were only one lever employed in the place of the four; the fulcrums *a*, *b*, *c*, *d*, divide this pressure equally among themselves.

133. When a weight is supported by a lever which rests on two props, the pressure upon both fulcrums is equal to the whole weight. This principle is sometimes applied in ascertaining the weight of a body too heavy for the steelyards. The body is suspended immovably near the center of a pole, and the steelyards are applied to each end of the pole separately, the other end meanwhile resting on its fulcrum. The two weights being added together, make the entire weight of the body. If the body is suspended exactly in the center of the pole, it will be sufficient to obtain the weight of one end and double it. The weight of the lever should, in both cases, be subtracted from the entire weight.

134. Since when a weight is suspended between two props, *the part sustained by each prop is inversely as the distance of the weight from it*, it follows that a load borne on a pole, between two bearers, is distributed in this ratio. As the effort of the bearers and the direction of the weight are always parallel, it makes no difference whether the pole is parallel to the horizon or inclined to it. Whether the bearers ascend or descend, or move on a level plane, the weight will be shared between them in the same constant ratio.

135. *Handspikes* and *crowbars* are familiar examples of levers of the first kind. A *hammer* affords an example of the *bent lever;* and shears, pliers, nutcrackers, and all similar instruments, are *double levers;* that is, they consist of two levers

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How can we ascertain the weight of a body too heavy for the steelyards? How when the body is suspended from the center of the pole? When a load is borne on a pole resting on the shoulders of each man, how is the part which each bears related to his distance from the weight? Give examples of *levers of the first* kind. Example of the bent lever, of *double levers.*

united. A pair of shears with long handles, like those used by tinners, exhibit very strikingly the increase of power gained by bringing the weight or substance acted on nearer to the fulcrum. The jaws of animals exhibit a similar property. An oar, applied to a boat rowed by hand, a wheelbarrow, and a door shut by the hand applied to the edge remote from the hinges, severally furnish instances of levers of the second kind, where the weight is between the fulcrum and the power.

136. The *crane* is a lever of the second kind which is much used when great weights are transported for a short distance, as heavy boxes of merchandize from a vessel to the wharf, or great masses of stone from the quarry to a car or boat. An example of the crane, on a small scale, is seen in the apparatus of a kitchen fire-place.

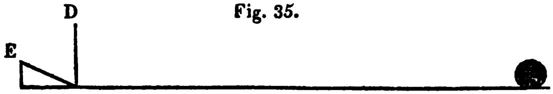
137. When one raises a ladder from the ground by one of the lower rounds, the ladder becomes a lever of the third kind, the power being applied between the weight and the prop. Since in all the mechanical powers, the power and weight have equal momenta, and since, in the third kind of lever, the weight has more velocity than the power, the power is as much greater than the weight, as the velocity with which it moves is less. The difficulty experienced in raising a ladder from the ground by taking hold of the lowest round, or of shutting a door by applying the hand to the side next to the hinges, shews the mechanical disadvantage under which a lever of this kind acts. Yet it is very useful in cases where it is required to give great *velocity* to the body moved. *Sheep shears*, consist of two levers of this kind united. Here the whole force required is so small that to save it is of no consequence, while so soft and flexible a substance as wool, requires the shears to be moved with considerable velocity. A pair of tongs is composed in the same manner; and therefore it is only a small weight that we can lift with them, especially when the legs are long.

138. One of the most remarkable applications of the third kind of lever, is in the *bones of animals*. These are levers, the joints are the fulcrums, and the muscles are the power. The muscles are endowed with a strong power of contraction, by which they are made to pull upon a tendon or cord, which

What is the cause of the great power of the tinners' shears? Give *examples of* levers of the second kind. What is the crane? Examples *of levers of the* third kind. To which kind of lever do the bones of *animals belong?*

is inserted in the bone near the fulcrum. Thus, the fore-arm moves on the joint near the elbow as a fulcrum, a little below which is inserted a tendon, connected with a muscle near the shoulder called the *deltoid* muscle. The arrangement may be well represented by attaching a small cord to one of the legs of a pair of tongs, near the joint. It will require a considerable force to lift the leg by pulling at the string, especially if the string be pulled in a direction nearly parallel with the leg, as it ought to be, since the tendon which lifts the fore-arm acts in such a direction with respect to the arm. The muscles therefore act, in moving the bones, under a double mechanical disadvantage, their force being applied both obliquely and very near the fulcrum. The force which the deltoid muscles exert in raising a weight held in the palm of the hand, is enormous, as will be comprehended from the following illustration. Let

Fig. 35.



AB represent the fore-arm, moving on the elbow-joint at A, and having the tendon inserted at C, which we will suppose to be one hundred times nearer to A than B is to A. Consequently, a weight of 1 lb. at B, would require a force at C, acting directly upwards, of 100 lbs. But the force of the tendon does not act *directly upwards* in the direction of CD, but very obliquely, as in the direction of CE, of which the part EA only can contribute to support the weight. Suppose this part to equal $\frac{1}{10}$th of the whole force CE, and it follows that the muscular force exerted to raise a weight of 1 lb. in the palm of the hand, would, were it to act without any mechanical disadvantage, be sufficient to raise a weight of 1000 lbs. Yet Dr. Young informs us, that a few years ago there was a person at Oxford, who could hold his arm extended for half a minute, with half a hundred weight hanging to his little finger.

139. But by giving to the muscle the position it has, the greatest possible *compactness of structure* is obtained, while by making it act so near the fulcrum, what is lost in force, is gained in *velocity;* and while the power acts through a small space, the hands are moved quickly through a great distance. In consequence of the dominion which man can gain over the

In what does the force reside which raises a weight held in the hand? What is the fulcrum? *Under what* mechanical disadvantage does the arm act? *How is this disadvantage* compensated?

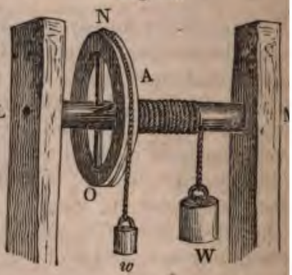
stronger animals, and especially over the great powers of Na ture, he has little occasion to exert great strength with his nake hands: the celerity of their movements, is to him a far mor important endowment.

CHAPTER IX.

MACHINERY CONTINUED.—OF WHEEL WORK.

140. When a lever is applied to raise a weight, or to over come a resistance, the space through which it acts at one tim is small, and the work must be accomplished by a successio of short and intermitting efforts. The common lever is, there fore, used only in cases where weights are required to be raise through small spaces. When a continuous motion is to b produced, as in raising ore from a mine, or in weighing th anchor of a vessel, some contrivance must be adopted to re move the intermitting action of the lever, and render it con tinual. The *wheel and axle*, in its various forms, fully answers this purpose. It may be considered as a revolving lever.

Fig. 36.



Thus in figure 36, DE, is an axle resting upon two supports, L and M; NAO is a wheel connected with the axle; W is the weight, which may be balanced by a weight hung to the circumference of the wheel, as *w*.

In the wheel and axle, the law of equilibrium is as follows

The power is to the weight as the diameter of the axle is the diameter of the wheel.

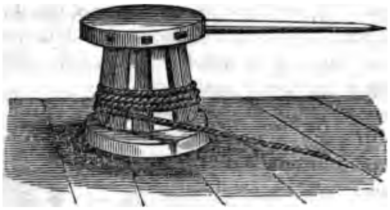
If the diameter of the wheel is ten times that of the axle, power of one pound will balance a weight of ten.

141. In numerous forms of the wheel and axle, the weigh is applied by a rope coiled upon the axle; but the manner i which the power is applied is very various, and not ofte

To what uses is the common lever restricted? What advantage ha the wheel and axle over it? Describe the wheel and axle from the fig *ure. What is the* law of equilibrium in the wheel and axle? To wha *is the weight usually* attached?

by means of a rope. The circumference of a wheel sometimes carries projecting pins, to which the hand is applied to turn the machine. An instance of this occurs in the wheel used in the steerage of a vessel. In the common *windlass*, the power is applied by means of a *winch* which corresponds to the radius of a wheel. The axis is sometimes placed in a vertical position, and turned by levers moved horizontally. The *capstan* of a ship (Fig. 37,) is an example of this. Levers answering to the radii of a wheel are inserted in holes mortised in the axis, and turned by several men working together. In some cases, as in the *treadmill*, the wheel is turned by the weight of animals walking on the circumference, with a motion like that of ascending a steep hill.

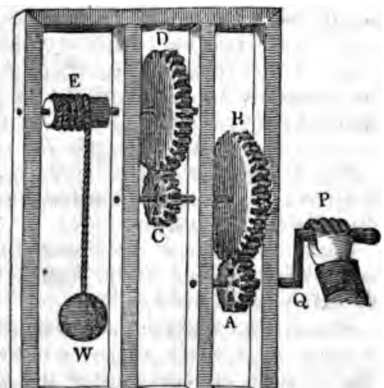
Fig. 37.



142. *In the* COMPOUND WHEEL AND AXLE, *the power is to the weight, as the product of the diameters of all the smaller wheels, is to the product of the diameters of all the larger wheels.*

Thus in Fig. 38, the power being applied to the winch PQ, acts upon the small wheel A, which acts upon the large wheel B, this upon C, and so on. Now if the diameters of the three smaller wheels, including that of the axle, be severally one fourth those of the larger wheels, (of which the diameter of the wheel described by the winch PQ, that is, twice PQ, must be considered as one,) then the

Fig. 38.

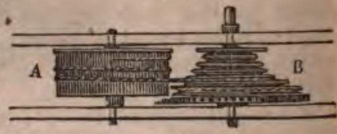


Specify the different ways in which the power is applied. How in the windlass? How in the capstan? How in the treadmill? What is the law of equilibrium in the compound wheel and axle? Explain by figure 38

power will be to the weight as $1 \times 1 \times 1 : 4 \times 4 \times 4$, that is, as 1 to 64; and a force of ten pounds applied at P will balance a weight of 640 pounds applied at W.

143. It is sometimes desirable to make a *variable* power produce a constant force. This may be done by making its velocity increase as its intensity diminishes. We have an example of this in the reciprocal action between the main spring and fusee of a watch. (Fig. 39.) The main spring is coiled up in the box A, and is connected with the fusee B by a chain. When the watch is first wound up, the spring acts with its greatest intensity, but then as the wheel B turns, it uncoils with the least velocity; but on account of the varying diameters of the wheels of the fusee, as the intensity of the spring is diminished, its effect is continually increased by acting on a larger wheel. In a similar manner a varying *weight* may be moved by a constant power.

Fig. 39.



144. *Examples.*

Ex. 1. The diameter of a wheel is $4\frac{1}{2}$ feet, and that of its axis $1\frac{1}{4}$ feet: what power will be required to balance a weight of 100 lbs.?

$$4\tfrac{1}{2} : 1\tfrac{1}{4} :: 100 : \tfrac{125}{4.5} = 2 \text{ lbs. } 12\tfrac{4}{9} \text{ oz. Ans.}$$

Ex. 2. What must be the diameter of a wheel by which a weight of 100 lbs. suspended by a rope going round an axle whose diameter is 1 foot, is balanced by a power of 12 lbs.?

$$12 \text{ lbs.} : 100 \text{ lbs.} :: 1 : \tfrac{100}{12} = 8\tfrac{1}{3} \text{ feet, Ans.}$$

Ex. 3. A power of 3 lbs. acts upon a wheel whose diameter is 6 feet; what weight will balance it upon an axle of 5 inches diameter? Ans. $43\frac{1}{5}$ lbs.

Ex. 4. A power of 5 lbs. balances a weight of 150 lbs. by means of a wheel 10 feet in diameter: what is the diameter of the axle? Ans. 4 inches.

Ex. 5. Four wheels, A, B, C, D, whose diameters are 5, 4, 3, 2 feet respectively, are put in motion by a power of 10 lbs. applied at the circumference of the wheel A; the wheels act upon each other by means of three smaller wheels, the diameter of each of which is 8 inches; the last wheel D, turns an

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How do we make a variable power produce a constant force? How exemplified in a watch?

axle whose diameter is 6 inches; what weight may be sustained by a rope going over the axle? Ans. 8,100 lbs.

Communication of Motion by Wheel Work.

145. Motion may be transmitted by means of wheel work in several different methods, the principal of which are, the friction of the circumference of one wheel, upon that of another—the friction of a band—and the action of teeth.

One wheel is sometimes made to turn another, by the mere *friction of the two circumferences.* If the surfaces of both were perfectly smooth, so that all friction were removed, it is obvious that either would slide over the surface of the other, without communicating motion to it. But, on the other hand, if there were any asperities, however small, upon their surfaces, they would become mutually inserted among each other, and neither the wheel nor axle could move without causing the asperities on its edge to encounter those which project from the surface of the other; and thus both wheel and axle would move at the same time. Hence, if the surfaces of the wheel and axle are by any means made rough, and pressed together with sufficient force, the motion of either will turn the other, provided the load or resistance be not greater than the force necessary to break off these small projections which produce friction.

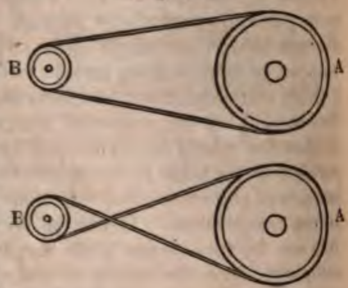
146. In some cases where great power is not required, motion is communicated in this way through a train of wheel work, by rendering the surfaces of the wheel and axle rough, either by facing them with buff leather, or with wood cut across the grain. The communication of motion between wheels and axles by friction has the advantage of great smoothness and evenness, and of proceeding with little noise; but this method can be used only in cases where the resistance is not very considerable, and therefore it is seldom adopted in works on a large scale. Dr. Gregory mentions an instance of a saw mill at Southampton, where the wheels act upon each other, by the contact of the end grain of the wood. The machinery makes very little noise and wears well, having been used not less than twenty years.

147. Wheel work is extensively moved by the *friction of a band.* When a round cord is used, any degree of friction may

What are the several methods of communicating motion by means of wheel work? *Explain the method* by the friction of the surface. What are the advantages of this method?

be produced, by letting the cord run in a sharp groove at the edge of the wheel. When a strap or flat band is used, its friction may be increased by increasing its width. The surface at the circumference of a wheel which carries a flat band, should not be exactly cylindrical, but a little convex, in which case if the band inclines to slip off at either side, it returns again by the tightening of its inner edge, as may be seen in a turner's lathe. When wheels are connected in the shortest manner by a band, they move in the same direction; if the band be crossed, they will move in opposite directions. (Fig. 40.) Wheels are sometimes turned by *chains* instead of straps or bands, and are then called *rag wheels*. The chains lay hold upon pins, or enter into notches, in the circumference of the wheels so as to cause them to turn simultaneously. They are used when it is necessary that the velocities should be uniform, and where great resistance is to be overcome, as in locomotive steam engines, chain water wheels, &c.

Fig. 40.



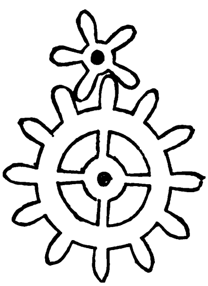
148. But the most common mode of moving wheel work, is by means of *teeth* cut in the circumference of the wheels. The wheels of necessity turn in opposite directions. The connexion of one toothed wheel with another is called *gearing*. In the formation of teeth, very minute attention must be given to their figure, in order that motion may be communicated from one wheel to another, without rubbing or jarring. If the teeth are ill matched, as in figure 41, when the tooth A, comes into contact with B, it acts obliquely upon it, and as it moves, the corner of B slides upon the plane surface of A in such a manner as to produce much friction, and to grind away the side of A, and the end of B. As they approach the position CD, they sustain a jolt the moment their

Fig. 41.

Describe the method of turning wheels by the friction of a band. What are *rag* wheels? What is gearing? What attention is to be given to the *figure of teeth*? Explain the inconveniences of badly constructed teeth as represented in figure 41.

surfaces come into full contact; and after passing the position CD, the same scraping and grinding effect is produced in the opposite direction, until by the revolution of the wheels the teeth become disengaged. To avoid these evils, the surfaces of the teeth are frequently *curved* so as to roll on each other with as little friction, and with as uniform force and velocity as possible. (Fig. 42.) Much pains and skill have been bestowed on this subject by mathematicians, with the view of ascertaining the kinds of curves which fulfil these purposes best.

Fig. 42.



Regulation of Velocity by Wheel Work.

149. Wheel work serves the purpose, not only of forming a convenient communication of motion between the power and the weight, but also of *regulating its velocity*. Thus, when the connexion is formed by means of a band, as in figure 42, the velocity of the wheel B, that carries the weight or sustains the pressure may be altered at pleasure, by altering the ratio between the diameters of the two wheels. If the diameters are equal, the wheels will revolve with equal velocity; if A remains the same, while the diameter of B is increased or diminished, the velocity of B will be increased or diminished in the same ratio; or if B remains the same, while the diameter of A is changed, the velocity of B will be changed in the same manner. We see familiar examples of the application of this principle in the common spinning wheel, and the turner's lathe. In the spinning wheel, a band passes round a large wheel and a small one called a spool, having the spindle for its axis; and in consequence of the great disparity in the size of the wheels, a great velocity is given to the spindle by a comparatively slow revolution of the wheel. In a turner's apparatus, machinery for spinning cotton, and the like, a large hollow cylinder, or *drum*, is fixed horizontally, which is kept revolving by the moving power, and from which, motion is conveyed by bands to lathes, spindles, &c., to which any required velocity is given, by altering the diameter of the small wheel that is connected with them and turns them. Sometimes a change of velocity

How are these evils obviated? Second object of wheel work to regulate velocity—explain how this is done. How exemplified in the spinning wheel and the turner's lathe. What is a drum? Use of a drum of conical form.

is effected by making the drum of a conical shape, a the velocity imparted to the lathe or the spindle, will be or less, according as the band proceeds from the l smaller part of the drum.

150. A more exact method of regulating the velocity tion, is by means of *wheels and pinions.* An example kind, is seen in Fig. 43, where A, B, C, are three whe *a*, *b*, *c*, are the corresponding pinions. As the leaves of the pinions successively pass between the teeth of the wheel, they must be equal and similar to them ; and since magnitudes have the same ratio to each other as their like parts, it follows that the number of teeth in a wheel, and of leaves in the pinion that acts upon it, express the ratio of the circumference or radius of the wheel to that of the Hence, in an equilibrium, the power multiplied by the of the numbers expressing the amount of teeth in all the respectively, is equal to the weight multiplied by the pro the several numbers denoting the leaves in each of the

Fig. 43.

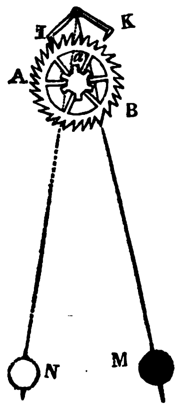
151. It is farther evident, that the velocity of a wh that of the pinion connected with its circumference, wil versely as the number of teeth in each. Thus in Fig the pinion *a* has 10 teeth, and the wheel B has 100, move ten times as fast as B. For the same reason *b* wi ten times as fast as C, so that, in this arrangement, the moves with 100 times the velocity of the weight. By v the ratio between the number of teeth in the pinion, number of teeth in the wheel with which it is connect may vary the velocity of any wheel at pleasure.

152. A familiar instance of this is afforded in the mec of a common clock. A pendulum by falling gains a q

Show how velocity is regulated by wheels and pinions. Sh *velocity is regulated* by means of the pendulum.

of motion sufficient to carry it on the other side to the same height as that from which it fell; and were it not for the resistance of the air and the impediments, a pendulum when once set in motion would continue to vibrate by its own inertia, and would thus afford, without the aid of any machinery, an exact measure of time. But, in order to continue its vibrations, some small force must be applied to it to compensate for the loss of motion from friction and resistance. This force is supplied to the pendulum of clocks by the *weight*, and an analogous force is supplied to the *balance wheel* of watches and chronometers by *springs*. In Fig. 44, let A B be a wheel having 30 teeth, and let N, M, be a pendulum, connected with the wheel by the *pallets* I, K; and to the axis *a*, let a weight be hung. It is evident that this weight, were there nothing to arrest it, would descend by the force of gravity with accelerated velocity. It *endeavors* thus to descend, and hence exerts the required force on the pallets of the pendulum. For, every time the pendulum performs a double vibration, (returning to the same point from which it set out,) a tooth of the wheel escapes,* and the wheel runs down until the next tooth strikes upon the pallet, and thus gives it the impulse which is necessary to keep up the vibrations.

Fig. 44.



153. It would seem therefore that, for beating seconds, only a single wheel is necessary; nor would any more be absolutely indispensable; but in this case the weight would descend so fast, as soon to reach the floor, and the clock would require to be wound up again every few minutes. Hence a series of wheels are interposed between the pendulum and the weight, by which the descent of the latter is retarded upon the principle explained in Art. 150, and the descent of the weight is slower in proportion as the series is more extensive. In cheap clocks, as some of those made with wooden wheels, the series is short, or the number of wheels employed for retarding the descent of the weight is small, and such clocks require fre-

Why does the pendulum continue to vibrate? Illustrate by figure 44. How many wheels are necessary to continue the beating of the pendulum? Why are more employed? What are the disadvantages of a small number of wheels?

* Hence this wheel is called the *scapement*.

quent winding up; but in clocks of finer workmanship, a greater number of wheels is interposed, and such clocks require to be wound up less frequently. Many go eight days, and some are made to go a whole year without winding.

Wheel Carriages.

154. In wheel carriages, wheels are not used as mechanical powers; for, since they move with the same velocity as the power which propels them, there is no mechanical advantage gained by them. When we shut a door by taking hold of the edge most remote from the hinges, the door becomes a lever of the second kind, and we act under a mechanical advantage. When we shut the door by applying the hand near the hinge, the door becomes a lever of the third kind, and we act under a mechanical disadvantage. There is, however, a point between the inner and outer edge, where the force would act without either advantage or disadvantage. In like manner, a carriage wheel is turned on the ground as on a hinge, by a force applied at its center of gravity; and, in passing over an obstacle, it rolls over it as a door turns on its hinges. The necessity of a certain amount of resistance or friction in the plane on which the wheel revolves is obvious, because otherwise there could be no fulcrum or hinge on which it could turn. Thus wheels moving on smooth ice, *slide* instead of turning; and when the power is applied to the circumference, if the friction is not sufficient to act as a fulcrum, the wheel turns without advancing, as a wheel turning in the air. Large wheels appear in theory to be much more advantageous than small ones. A large wheel will better surmount stones and other obstacles, since in turning over, the ascent is more gradual and easy. In passing over holes, it sinks less, and occasions less jolting and less expenditure of power. The wear of small wheels exceeds that of large ones; for if we suppose a wheel to be three feet in diameter, it will turn round twice, while a wheel of six feet in diameter turns round once. Of course its tire will come twice as often in contact with the ground, and its spokes will twice as often have to support the weight of the load. So that by calculation, it should last but

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How long will some clocks go without winding? In what carriages is any mechanical advantage gained? To what point is the force applied? What constitutes the fulcrum on which the wheel turns? Why is any resistance necessary? How would wheels move on smooth ice? Case of a wheel turning in the air. State the comparative advantages of large and small wheels.

half the length of time. On these accounts it would be advantageous to augment the diameter of wheels to a great extent were it not for certain practical limits which it is found useful not to exeeed. One of them is found in the nature of the materials which we are obliged to use, and which if employed to make wheels of great size, at the same time preserving the requisite strength, would render them cumbersome and heavy for use. Again, a wheel should seldom be of such dimensions, that its center is higher than the breast of the horse or other animal by which it is drawn; because when this is the case, the horse draws obliquely downwards as well as forward, and expends a part of his strength against the ground.

155. The *line of draught* should not be horizontal, but inclined upwards towards the breast of the horse, in an angle not less than 15 degrees with the horizon. This brings the strain nearly at right angles with the collar, whereas a horizontal draught lifts the collar upwards, by which the force is wasted and the animal is choked.

The effect of suspending a carriage on *springs*, is to equalize the motion by causing every change to be more gradually communicated to it, and to obviate shocks. Springs are not only useful for the convenience of passengers, but they also diminish the labor of draught; for whenever a wheel strikes a stone, it rises against the pressure of the spring, in many cases without materially disturbing the load; whereas without the spring, the load, or a part of it, must rise with every jolt of the wheel, and will resist the change of place with a degree of inertia proportionate to the weight, and the suddenness of the percussion. Hence springs are highly useful in baggage wagons and other vehicles used for heavy transportation.

A pair of horses draw more advantageously abreast than when one is harnessed before the other. In the latter case, the forward horse, being attached to the ends of the shafts, draws in a line nearly horizontal; consequently he does not act with his whole force upon the load, and moreover expends a part of his force in a vertical pressure on the back of the other horse.

What practical disadvantages attend small wheels? What attend large wheels? What angle should the line of draught make with the horizon? What are the disadvantages of having the line of draught horizontal? Point out the uses of springs in carriages. Why are springs useful in baggage wagons? Should two horses be harnessed side by side, or one forward of the other?

CHAPTER X.

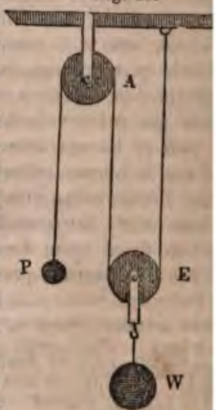
MACHINERY CONTINUED—THE PULLEY, INCLINE PLANE, SCREW, AND WEDGE.

THE PULLEY.

157. *A* PULLEY *is a small grooved wheel movable about a p the pivot itself being at the same time either fixed or mov*

Fig. 45.

The *fixed* pulley is represented in Fig. 45. By it no mechanical advantage is gained, but its use consists in furnishing a convenient mode of changing the direction of the power. Thus, it is far more convenient to raise a bucket from a well by drawing downwards, as is the case where the rope passes over a fixed pulley above the head, than by drawing upwards, leaning over the well. By means of the pulley, great facilities are afforded for managing the rigging of a ship. The sails at mast head can be easily raised, while the hands stand upon the deck; whereas, without the aid of ropes and pulleys, the same force removed to the mast head would operate under very great disadvantages. Similar facilities are afforded by this kind of apparatus for raising heavy weights, as boxes of merchandize, or heavy blocks of stone in building.

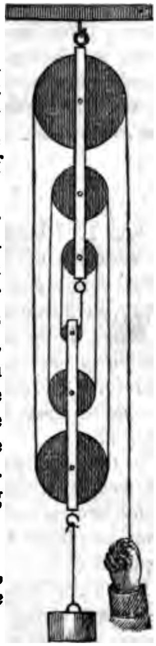
Fig. 46.

Fire escapes sometimes consist merely of a pulley fixed near the window of the apartment, around which a rope may be easily placed, having a basket attached to the end. The man seats himself in the basket, grasping, at the same moment, the rope on the other side of the pulley, and thus he lets himself gradually down.

158. The *movable* pulley is attended with a mechanical advantage, so that

Define the pulley. Is any mechanical advantage gained by the f *pulley?* What is its use? Give examples. How are fire escapes *structed?*

a comparatively small power may
ɔ raise great weights. Fig. 46, rep-
novable pulley E in connexion with a
ʟ. The weight W bears equally upon
rts of the rope, and consequently that
s against the power P, sustains only
ight. An equilibrium will therefore
ed when the power is equal to half
t.

Fig. 47.



47, *blocks* of pulleys are represent-
ich the weight is distributed over a
umber of parts of the rope; each
fore sustains a proportionally smaller
the load, and yet one of these parts
acts immediately against the power.
power will be as much less than
t, as the number of parts of the rope
than unity. Thus, where there are
three on each side, a power of one
ll balance a weight of six pounds.
ciple is generalized in the following
n.

pulley an equilibrium is produced,
power is to the weight as one to the
ropes.

'he ascent of the weight is in all cases retarded in
ı as the efficacy of a given power is increased.
, in using any system of movable pulleys, the whole
the pulleys themselves, together with the resistance
d by the rigidity and friction of the rope, acts against
, and so far lessens the weight which it is capable of
In the more complex system of pulleys, it is estima-
ıt least two thirds of the power is expended on the
y itself. On account therefore of slowness of the
hich the weight receives, and the loss of power from
ance of the ropes and blocks, such systems of pul-
eldom employed. It is only in raising vast weights,
arge ships, or great masses of stone from a quarry,

echanical advantage gained by the movable pulley? Describe
42. Also by figure 41. When is an equilibrium produced in
How is the velocity of the weight affected by increasing the
the *power? Point out* the sources of loss or resistance in the

that they are ever used. For managing the rigging of a s the combination usually employed consists of not more two or three movable pulleys. From its portable form, h ever, its cheapness, and the facility with which it can be plied, especially in changing or modifying the directio motion, the pulley is one of the most convenient and usef the mechanical powers.

160. *Examples.*

Ex. 1. I wish to raise a block of stone weighing two t or 4480 lbs. but can command a power only equal to $746\frac{2}{3}$ l What number of pulleys shall I require? $746\frac{2}{3} : 4480 :: 1$ ropes, or 3 movable pulleys, Ans.

Since the number of ropes (or parts of the rope,) must b and since each movable pulley has two ropes, as in Fig. therefore the number of movable pulleys must be *three* the block must be analogous to one of those represente Fig. 47.

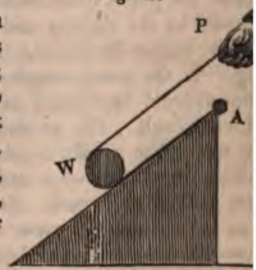
In this and other similar estimates, no allowance is mad the weight of the pulleys and other parts of the machi which are raised along with the weight. The amount of t must be added to the weight in order to ascertain the po required.

Ex. 2. By a system of pulleys containing 6 movable pull the same string going round the whole, as in Fig. 47, w power will be necessary to sustain a weight of 112 l Ans. $9\frac{1}{3}$.

THE INCLINED PLANE.

161. Let Fig. 48, represent an Inclined Plane, whose length is AC, height AB, and base BC; and let W be a weight drawn up this plane by a power applied at P, and acting parallel to the plane. Then an equilibrium is produced, when *the power is to the weight, as the height of the plane to its length.*

Fig. 48.



Is the combination of pulleys usually employed simple or comp Why is the pulley accounted one of the most useful among the mec ical powers? How is the power to the weight in the Inclined Plan

162. The inclined plane becomes a mechanical power in consequence of its supporting a part of the weight, and of course leaving only a part to be supported by the power. Thus the power has only to encounter a *portion* of the force of gravity at a time,—a portion which is greater or less, according as the plane is more or less elevated. When a plane is perfectly horizontal, it sustains the entire pressure of a body that rests on it; that is, the pressure on the plane is equal to the whole force of gravity acting on the body. As one end of the plane is elevated, this force is resolved into two, one of which is parallel and the other perpendicular to the plane. In proportion as the plane is more elevated, the part of the force which acts parallel with the plane is increased, until, when the plane becomes perpendicular to the horizon, it no longer sustains any portion of the weight, and the latter descends with the whole force of gravity.

163. The simplest example we have of the application of the Inclined Plane, is that of a plank raised at the hinder end of a cart for the purpose of rolling in heavy articles, as barrels or hogsheads. The force required to roll the body on the plank, setting aside friction, is as much less than that required to lift it perpendicularly, as the height of the plane above the ground is less than its length. Every one knows how much the facility of moving heavy loads is increased by such means, and how the force required to move them is diminished, by increasing the length of the plane while the height remains the same. Long inclined planes, constructed of plank, are frequently employed in building, especially where high walls are built of large masses of stone, the materials being trundled up the plane on wheel barrows, or transported on heavy rollers. It is even supposed, that in building the pyramids of Egypt, the huge masses of stone were elevated on an inclined plane. *Roads* also, except when they are perfectly level, afford examples of this mechanical power. When a horse is drawing a heavy load on a perfectly horizontal plane, what is it that occasions such an expenditure of force? It is not the weight of the load, except so far as that increases the friction; for gravity, acting in a direction perpendicular to the horizon, can

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How does the inclined plane become a mechanical power? Explain how the inclined plane moderates the force of gravity. Example of a plank placed at the hinder end of a cart—how much is the force required to raise the weight diminished by the plank? What is the effect of lengthening the plane while its height remains the same? Explain the use of long inclined planes in building. How are the principles of the inclined plane exemplified in roads?

oppose no resistance in the direction in which the load is moving. The answer is, that the force of the horse is expended chiefly in overcoming friction, and the resistance of the air. But when a horse is drawing a load up a hill, he has not only these impediments to encounter, but has also to overcome more or less of the force of gravity; that is, he *lifts* such a part of the load as bears to the whole load the same ratio, that the perpendicular height of the hill bears to its length. If the rise is one foot in twenty, he lifts one twentieth of the load, and therefore encounters so much resistance in addition to the resistances which he had to overcome on the horizontal plane. If the ascent were one foot in four, and the load were a ton, the additional force required above what would be necessary on level ground, would be 560 pounds.

164. *Railway's* afford another striking exemplification of the principles of the Inclined Plane. By means of them the irregular surface of a country, however hilly and uneven, is reduced to horizontal levels and inclined planes. These are sometimes inclined at so low an angle, that the tendency of the cars down the plane, is only just sufficient to balance their friction, and they would remain at rest of themselves in any part of the plane, while a small force would move them either way. In other places the Inclined Planes are very steep for a short distance; and the cars ascending upon them are sometimes drawn up by means of a power, (a steam engine for example,) stationed on the summit, and sometimes cars descending on one side, are made to draw up others on the other side, the two being connected by a chain or rope which passes round a pulley on the summit. It is said that on a well constructed horizontal railway, a single horse will draw a load weighing ten tons. A steam engine mounted on wheels, called the *locomotive*, is sometimes used instead of horse power on railways. This answers every condition of a perfect force, being capable of being exactly proportioned to the weight to be carried, whether one ton or a thousand tons, and moving with immense speed, without ever tiring.

165. The Inclined Plane has been very advantageously substituted for *Locks* on Canals. The method, in general, is to construct around the Falls a railway in the form of an inclined

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How are the principles of the inclined plane exemplified in railways? What load will a horse draw on a railway? How are loads drawn up steep ascents? What is the locomotive? What are its peculiar advantages as a moving force?

; and then the boat being floated into a large cistern of r, the whole is placed on the inclined plane, (the lower end e cistern being supported so as to keep the surface of the r level,) and is rolled up or down the plane, either by ng descending draw up ascending loads, or by drawing e ascending cistern with its boat by means of machinery. e latter case, the water fall itself acting on a wheel, may ade to afford the requisite power.

6. The *motion of bodies descending down inclined planes*, bject to the same law of gravity as bodies falling freely; is, it is uniformly accelerated. Consequently, here, as in ase of bodies falling without impediment, *the spaces de-ed are proportioned to the squares of the times*, and to *the es of the velocities acquired.* (Arts. 59 and 63.)

7. *The velocity acquired in falling down an inclined plane same as that acquired in falling through the perpendicular t of the plane.*

hen a plane is but slightly elevated, as in rail-roads, the eration, though constant, is comparatively slow; but after g freely through such a distance as several miles, the mo-may become exceedingly rapid. A very remarkable ex-e of the acceleration of bodies descending down inclined s, occurs at the *Slide of Alpnach* in Switzerland. On nt Pilatus, near Lake Luzerne, is a valuable growth of fir , which, on account of the inaccessible nature of the tain, had remained for ages uninjured, until within a few , a German engineer contrived to construct a trough in rm of an inclined plane, by which these trees are made scend by their own weight, through a space of eight or miles from the side of the mountain to the margin of the

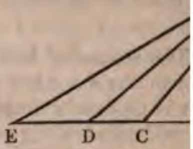
Although the average declivity is no more than about oot in seventeen, and the route often circuitous and some-horizontal, yet so great is the acceleration, that a tree nds the whole distance in the short space of six minutes. spectator standing by the side of the trough, at first is on the approach of a tree, a roaring noise, becoming r and louder; the tree comes in sight at the distance of

en bodies descend inclined planes, at what rate are they accelera- How are the spaces proportioned to the times? How does the ve- acquired by falling down an inclined plane compare with that ac- d by falling freely through the same height? Relate the circum- es of the *Slide of Alpnach?*

half a mile, and in an instant afterwards shoots past noise of thunder and the rapidity of lightning. Wh happens to "bolt" from the trough, it cuts the stand quite off.

168. It takes as much longer for a body to descend down an inclined plane, than to fall through its perpendicular height, as the length of the plane exceeds its height. Thus, in Fig. 49, a body in descending successively down the planes AC, AD, AE, would acquire in each case the same velocity, being the same as it would acquire by falling do but the times of describing these several lines would portioned to their respective lengths.

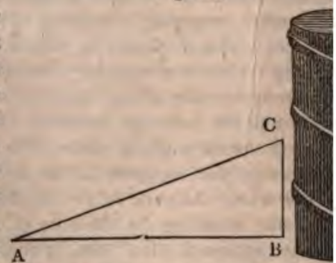
Fig. 49.



THE SCREW.

169. When a road, instead of ascending a hill winds round it to the summit, so as to lengthen the plane, and thus aid the moving force, the Inclined Pl comes a Screw. In the same manner a flight of stair ing around the sides of a cylindrical tower, either w without, affords an instance of an inclined plane so mo to become a screw. These examples show the strong which subsists between these two mechanical powers; or rather, they show that the screw is a mere modification of the Inclined Plane. This correspondence between the Inclined Plane and the Screw is exhibited in the annexed figure. The distance between two contiguous threads of a screw, corresponds to the *heig*

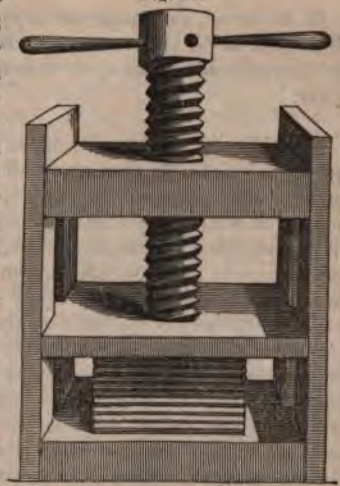
Fig. 50.



How much longer does it take for a body to descend down an plane than to fall through the perpendicular height of the plane *trate by figure 50.* The *Screw*—how is its principle exhibited i *winding around a hill?* How by a flight of stairs?

inclined plane, and the circumference of the cylinder corresponds to the *base* of the same plane; hence the forces necessary to produce an equilibrium in the screw, are the same as in the inclined plane. Thus, let the inclined plane ABC be wrapped round a cylinder, the circumference of whose base is equal to the line AB; then the point A being placed on A′, the point B will come round to A′, and the point C will fall on C′, and the line AC will trace out the thread of the screw on the surface of the cylinder as far as C′, and may be continued in the same manner. It will be remarked that the power here acts parallel to the *base* of the inclined plane. Thus in figure 51, the power is applied to the handle, which revolves parallel to the base of the screw, or the base of the inclined plane of which the screw is formed.

Fig. 51.



170. *In the screw, an equilibrium is produced when the power is to the weight, as the distance between two contiguous threads is to the circumference of the base.*

By inspecting figure 50, it will be seen that "the distance between two contiguous threads," is the height CB of the inclined plane ABC, while "the circumference of the base" is the base AB of the same plane. The law of equilibrium of the screw is therefore the same as in the inclined plane when the power acts in a direction parallel with the base; in this case the power being to the weight *as the height of the plane to the base.*

Show how the screw is formed by winding an inclined plane around a cylinder. What part of the plane corresponds to the distance between the threads? To what line does the power move parallel? What is the law of equilibrium in the screw? How is this law analogous to that of the inclined plane?

171. The power, however, is not always applied directly to the circumference of the screw, but frequently at the end of a lever inserted into the screw, as in figure 51, and as in the common cider press. Hence a more general law of equilibrium is as follows:

In the screw, an equilibrium is produced when the power is to the weight, as the distance between two contiguous threads is to the circumference of the circle described in one revolution of the power.

172. The Screw is generally employed where severe pressure is to be exerted through small spaces, and is therefore the agent in most presses. Being subject to great loss from friction, (upon which, however, its chief utility depends, as will be shown hereafter,) it usually exerts but a small power of itself but derives its principal efficacy from the lever, or from wheel-work, with which it is very easily combined. Thus, in figure 51, were the power applied directly to the screw, the mechanical advantage gained would hardly more than compensate for the loss by friction; but by means of the lever, (which may be lengthened or shortened at pleasure,) the power is greatly increased. The *endless screw* is represented in figure 53. It is used in connexion with toothed wheels. By means of the *endless screw*, combined with the wheel and axle, a very powerful force may be exerted; and as the mechanical power of the screw depends upon the relative magnitude of the circumference through which the power revolves, and the distance between the threads, it is evident that, to increase the efficacy of the machine, we must either increase the length of the lever by which the power acts, or diminish the distance between the threads. Although, in theory, there is no limit to the increase of the mechanical efficacy by these means, yet practical inconvenience arises from the great space over which a very long lever traverses. If, on the other hand, the power of the machine is increased by diminishing the distance between the threads, and of course their size, the thread will become too slender to bear a great resistance. The cases in which it is necessary to increase the power of the machine, being those in

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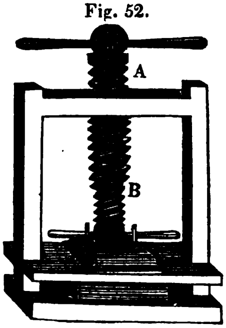
What is the general expression of the law, when the power acts at the end of a lever? For what purpose is the screw used? Is it commonly employed alone, or in connexion with one of the other mechanical powers? Describe the endless screw? Explain its principle. What practical inconvenience arises from the use of a very long lever?—Also from diminishing the distances of the threads too much?

which the greatest resistances are to be overcome, the object will evidently be defeated, if the means chosen to increase that power deprives the machine of the strength which is necessary to sustain the force to which it is to be submitted.

173. These inconveniences are remedied by *Hunter's Screw*, which, while it gives to the machine all the requisite strength and compactness, allows it to have an almost unlimited degree of mechanical efficacy. This screw is composed of a smaller and a larger thread, the former turning *upwards*, while the latter turns downwards with a little greater velocity, and consequently the screw, on the whole, advances with the *difference* between the larger and the smaller threads; and since this difference may be small to any extent, so the efficacy of the power may be increased indefinitely. It will be seen, however, that the motion of such a screw is exceedingly slow. Thus, in figure 52, A descends, while B, playing in a concave screw in A, ascends; but the distance between the threads of A being greater than the distance between those of B, the screw, on the whole, advances with the difference. Suppose that A has 20 threads in an inch, and B 21; then, during one revolution, A will *descend* through the 20th, while B *ascends* through the 21st part of an inch. The compound screw, therefore, will advance through a space equal to the difference; that is, through a space equal to $\frac{1}{20}-\frac{1}{21}=\frac{1}{420}$th of an inch. This small space is, therefore, in effect, the distance between two contiguous threads; and the power of the machine is, as usual, expressed by the number of times their distance is contained in the circumference described in one revolution of the power. For example, let the circumference of the circle be one foot; then $12\div\frac{1}{420}=5040=$ the weight or resistance, the power being 1; or, in other words, the efficacy of the power is increased five thousand and forty times.

Fig. 52.



174. It is obvious, however, from principles already explained, that the power will in this case move over 5040 times as great a space as the weight. It is on this principle that the

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Explain the principle of Hunter's Screw. By what is the power of the *machine expressed?*

screw affords the means of measuring very minute spa
hence is derived the *Micrometer Screw.* The very s
tion which may be imparted to the end of a screw, v
power moves over a space vastly greater, renders it p
adapted to this purpose. For example, suppose a scr
so cut as to have 50 threads in an inch: then each re
of the screw will advance its point through the 50t
an inch, and if that point acted against a thread or
would move it over a graduated space only that dista
whole revolution of the screw. Now suppose the hea
screw to be a circle an inch in diameter, and of cour
thing more than three inches in circumference. The
ference may easily be divided into a hundred equal pa
tinctly visible; and if a fixed index be applied to it,
dredth part of a revolution of the screw may be obse
noting the passage of one division of the head under th
But the hundredth part of a revolution carries the poin
screw only through the ($\frac{1}{100}$ of $\frac{1}{50}=$) $\frac{1}{5000}$th part of
Such an apparatus is frequently attached to the limbs
ated instruments, for the purposes of astronomical a
observations; by which means, a portion of the gradu
no greater than the 100th part of a second, can be es

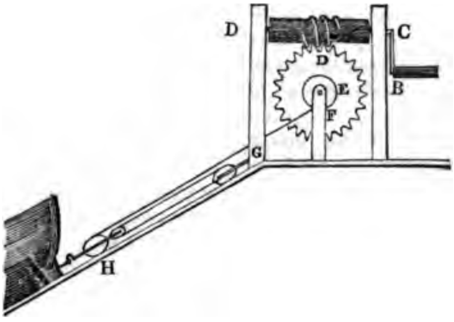
In like manner, any other small space may be meas
the aid of the Micrometer Screw. Thus, any aliquo
a pound, or an ounce, in the steelyards, may be found b
ing the screw to the counterpoise, so as to move it slo
the space between two notches, and at the same time p
by an index on its head, the exact portion of the sp
which it passes.

175. Several of the mechanical powers are frequen
bined in the same machine, and great works are somet
complished by a comparatively small force, carried ov
portionally greater space. The manner in which this i
exemplified in the figure annexed to the following prob

A shipwright wishing to haul a ship upon the sto
ployed a machine, combining the lever, the screw, th
and axle, the pulley, and the inclined plane, as repres
the annexed diagram.

To what use is the micrometer screw applied? Give an ex
its use in measuring 1-5000th part of an inch. What other sm
may be measured by it? What use is made of the *endless scre*
different mechanical powers are sometimes combined in the
chine?

Fig. 53.



The handle of the winch BC= 18 inches.

The distance of the threads on CD=1 inch.

The diameter of the wheel ED =4 feet.

The diameter of the axle EF =1 foot.

G is a fixed, and H a movable pulley, the number of strings=4.

Height of the plane equals half its length.

Allowing a man to turn on the handle B with a power equal to 100 lbs., how much force could he exert on the ship ?

By Art. 171. 100 lbs. exerted at B would become, at D,	11309.76
And since the diameter of the wheels is four times that of the axle,	×4
	45239.04
Again, this is rendered four-fold by the four strings of the pulley,	4
	180956.16
Finally, this is doubled by the plane,	2
	361812.32

Hence, the force exerted on the ship would amount to more than 361812 lbs., or more than 161½ tons.

THE WEDGE.

176. If instead of moving a load on an inclined plane, the plane itself is moved beneath the load, it then becomes a Wedge. Thus, if a perpendicular beam have one end resting upon an inclined plane, (the beam being so secured as to be capable of moving only up and down,) and the plane be drawn

How does the inclined plane become the wedge? How much less force is required to lift a weight by means of the wedge, than by a force *applied directly to it?*

under it, the beam will be elevated; and the power required to effect this will be to that required to raise the beam when applied directly to it, *as the height of the plane to its length*:—or, considering the plane as a half wedge, the proportion will be, *as half the back of the wedge to its length.*

177. In the arts and manufactures, wedges are used where an enormous force is to be exerted through a very small space. Thus it is resorted to for splitting masses of timber or stone. Ships are raised in docks by wedges driven under their keels. The wedge is the principal agent in the oil mill. The seeds from which the oil is to be extracted are introduced into hair bags, and placed between planes of hard wood. Wedges inserted between the bags are driven by allowing heavy beams to fall on them. The pressure thus excited is so intense, that the seeds in the bags are formed into a mass nearly as solid as wood. Instances have occurred in which the wedge has been used to restore a tottering edifice to its perpendicular position. All cutting and piercing instruments, such as knives, razors, scissors, chisels, nails, pins, needles, awls, &c. are wedges. The angle of the wedge, in these cases, is more or less acute, according to the purpose to which it is applied. In determining this, two things are to be considered—the mechanical power, which is increased by diminishing the angle of the wedge; and the strength of the tool, which is always diminished by the same cause. There is, therefore, a practical limit to the increase of the power, and that degree of sharpness only is to be given to the tool, which is consistent with the strength requisite for the purpose to which it is to be applied. In tools intended for cutting wood, the angle is generally about 30°; for iron it is from 50° to 60°; and for brass, from 80° to 90°. Tools which act by pressure may be made more acute than those which are driven by a blow; and, in general, the softer and more yielding the substance to be divided is, and the less the power required to act upon it, the more acute the wedge may be constructed.

178. In many cases, the utility of the wedge depends on that which is entirely omitted in the theory, viz. the *friction* which arises between its surface and the substance which it

In what cases is the wedge used in the arts? Give examples of its use in splitting hard substances—in making oil from seeds—in raising buildings to a perpendicular position, &c. What instruments exemplify *the wedge?* How is the power of a cutting instrument increased? What *degree of acuteness* is necessary?

s. This is the case when pins, bolts, or nails, are used nding the parts of structures together; in which case, it not for the friction, they would recoil from their places .il to produce the desired effect. Even when the wedge d as a mechanical engine, the presence of friction is ab-ly indispensable to its practical utility. The power gen- acts by successive blows, and is therefore subject to con- intermission, and but for the friction, the wedge would re- etween the intervals of the blows with as much force as been driven forward, and the object of the labor would ntinually frustrated.

). The following principle is of great importance in re- to all the mechanical powers, and deserving of particular .on.

ach of the mechanical powers, and in every machine, the and weight balance each other, when the power moves as faster than the weight as its quantity of matter is less.

can, therefore, make a small power raise a very great t, by so connecting it with the weight, as to make it over a very great, while the weight moves over a very space. By reviewing the several mechanical powers, all recognize the operation of this principle in each of

). In *levers* of the first and second kind, (Figs. 24, 26,) wer being applied at the extremity of the longer arm and r from the fulcrum than the power, moves over a propor-ly greater space as the lever turns on its fulcrum; but in ver of the third kind, (Fig. 27,) the power being applied : the fulcrum than the weight, moves with less velocity he weight, and consequently acts under a mechanical dis-tage, and requires to be proportionally greater than the t.

. In the *wheel and axle*, (Fig. 36,) as both the wheel and le revolve in the same time, it is obvious that the power d at the circumference of the wheel must move as much than the weight, as the circumference of the wheel is r than that of the axle.

. In the *pulley*, when the rope merely passes over a fixed ; *(as in Fig. 45,)* the power and weight move over the

same space, and no mechanical force is either gained or lost; but in the movable pulley represented in Fig. 46, the strings that raise the weight are equally shortened, and the power is lengthened by an amount equal to that by which the several parts are shortened; consequently, the power moves as much faster than the weight as the number of ropes is greater than unity. When the number of movable pulleys is great, the great space over which the power must move in order to raise the weight over a comparatively small space, presents a practical inconvenience. (See Fig. 47.)

183. In the *inclined plane*, the greater the length of the plane in proportion to its height, the slower will be the perpendicular ascent of the weight. For example, if the length of the plane be twice its height, the power must move over twice the space that it would if it rose perpendicularly, and hence the mechanical advantage gained is in the same ratio, that is, the power required is so much less than the weight.

184. In the *screw*, while the power performs one complete revolution, the weight is elevated only the distance between two contiguous threads. Hence, when the power is applied at the end of a long lever, and the distance between two contiguous threads is small, the forward motion of the screw is very slow, while the power traverses a great space.

185. In a combination of the mechanical powers, such as that represented in Fig. 53, we see the same principle very strikingly exhibited. Here the power moves 3619 times as fast as the weight, and the mechanical advantage gained is in the same ratio.

186. Finally, in the *wedge*, the power of overcoming resistances is proportioned to the *acuteness* of the wedge; and the distance to which the parts are separated, that is, the space over which the weight moves, when compared with the space through which the power, (namely, the wedge itself in the direction of the power,) moves, is constantly diminished as the acuteness of the wedge is increased.

How is the friction of the wedge essential to its utility? State the comparative velocity of the power and weight in all machines. How can we make a small power raise a great weight? How is this principle exemplified in the lever? in the wheel and axle? in the pulley? in the inclined plane? in the screw? in the wedge?

CHAPTER XI.

MACHINERY CONCLUDED.

187. Archimedes is said to have boasted to King Hiero, that "if he would give him a place to fix his machine, (που στῶ,) he would move the world." Yet there can be no machine by the aid of which Archimedes could move the world, in any other way, than by moving, himself, over as much more space than that over which he moved the earth, as his weight was less than that of the whole earth. If Archimedes had received the place he desired, and had also employed what was equally indispensable, a machine which operated free of all resistance, he must have moved with the velocity of a cannon ball, to have shifted the earth only the twenty-seven millionth part of an inch in a million of years.

188. From the foregoing principles it will be inferred, that no *momentum*, or effective force, is gained by any of the mechanical powers, or by any machine. If a man with his naked hands, can lift to a given height, as one foot, only 150 pounds in one second, it is impossible for him to perform any more labor than this by any mechanical contrivance. On the contrary, when the structure of the machine is complicated, there is a loss of force, by employing the machine instead of the naked hands, proportioned to the resistance of the parts of the machine itself. It is to be remarked, however, that this doctrine proceeds on the supposition that the *useful effect* produced is estimated from the joint product of the *force*, *velocity*, *and time*. A convenient method of estimating different forces is to draw a heavy weight out of a well, by a rope passing horizontally over a fixed pulley, near the top of the well. Suppose that a man can draw up a rock weighing 100 lbs. through the space of 50 feet in one minute. He would, of course, be able to draw up ten such masses in ten minutes, weighing in all 1000 pounds. Now by passing the rope over five pulleys, (allowing nothing for the friction of the pulleys,) he might with the same force lift the whole 1000 pounds at once; but it would rise ten times as slowly as the 100 pounds did before, and consequently

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What did Archimedes boast? On what principle could he have moved the world? How much could he have moved it? Is any momentum gained by machinery? How is the useful effect estimated? By what means are different forces estimated? Example in lifting a rock out of a well.

would be ten minutes in reaching the top. Therefore, in a given time, it appears that the man would raise the same weight through a given space, with or without the aid of machinery. In the former case, the 100 lbs. might have been raised during the ten minutes through the space of 500 instead of 50 feet; but $100 \times 500 \times 10 = 1000 \times 50 \times 10$; so that the labor performed would have been the same in both cases. Let us suppose that P is a power amounting to an ounce, and that W is a weight amounting to 50 ounces, and that P elevates W by means of a machine. In virtue of the property already stated, it follows, that while P moves through 50 feet, W will be moved through 1 foot; but in moving P through 50 feet, *fifty distinct efforts* are made, by each of which, if applied directly, 1 ounce would be moved through 1 foot.

189. *What then*, it may be asked, *are the advantages gained by Machinery?* The advantages are still very great, for the following reasons.

(1.) By the aid of machinery *we can frequently apply our force to much better purpose*. Thus, in lifting a weight out of a well, or in raising ore out of a mine, it is obvious with how much more effect a man can work at the arm of a windlass than he could draw directly upon the rope, stooping over the well. So in raising a rock from its bed by means of a handspike or crowbar, we can easily see how much more effectually we can bring our force to bear upon it, than we could do by our naked hands.

(2.) By the aid of machinery, a man may be able to perform works to which his naked strength would be wholly incompetent. Thus, as in the preceding example, one might be able to lift a rock from its bed with a handspike, upon which he could make no impression with his naked hands; or, by means of pulleys, he might raise a box of merchandize from the hold of a ship, which he could not start at all with his unassisted force. In each of these cases, *if the weight could be divided into small parcels*, and if the force could be as advantageously applied without machinery as with it, the labor would be performed as easily in a given time in one way as in the other. But it might not be possible, or at least convenient thus to divide it. Or if, instead of dividing it into a number of parcels,

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What are the advantages gained by machinery? Examples in raising ore from a mine, or in lifting weights out of a well, or a rock from its bed. Show how a man may perform works by the aid of machinery *to which his naked* strength is unequal. Why is there no gain of force *in such cases?*

ne number of men could act directly upon a weight at he amount of labor which they would all exert in rais- weight without machinery, would be the same as that the single man before supposed would exert with his iery. But it might not be convenient to assemble so iands at a time; or perhaps such a number could not idvantageously together. A farmer has many occasions ng or removing great weights when his laborers are not n number than two or three in all. These must there- rform the labor of 50 times as many men by being 50 is long about it. Thus, in the example given on page f a combination of the mechanical powers employed to ship on the stocks, where a single man turning on a with the force of 100 lbs. exerts a force on the ship ing to 161½ tons, the ship would move as much slower e hand, as 100 lbs. is less than 161½ tons; and conse- a great length of time would be required for an indi- to perform this labor, even supposing no resistance were tered from the machinery itself.

Machinery frequently enables a man to exert his *whole* n circumstances where, without such aid, he could em- it a part of it. Thus, in winding silk or thread, to turn e reel might not require one fiftieth part of the force the laborer was capable of exerting. Suitable machine- ld enable him to turn fifty spools at once.

But the most striking advantage of machinery is not in the facilities which it lends to the personal strength : It lies in this, that it affords the means of calling in assistance the superior powers of the horse and the ox, er, of wind, and especially of steam. Here we find the nce of mechanical contrivances fully exhibited; and no else has the inventive genius of man displayed itself to t advantage. But here, as in all other cases, the various iations of mechanical powers *produce* no force; they *pply* it. They form the communication between the power and the body moved; and while the power itself incapable of acting except in one direction, we are able, ns of cranks, levers, and toothed wheels, to direct and that force to suit our convenience or necessities. Every y see examples of this in the construction of the most n saw mill or flour mill, turned by water. In a mill for g wheat, the stones are required to move horizontally,

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how machinery enables a man to exert his whole force. What *st striking advantage* gained by it? Show the use of machinery *ing the direction of the force.* Also in regulating its velocity.

while the action of the water fall is perpendicular. We there fore receive the whole force on the circumference of a whee and transmit it through several intermediate wheels to the re volving stone, where the grinding is performed. So in a sa mill, the water first communicates a *rotary* motion to the whe and this motion is converted by means of a crank into what called a *reciprocating* motion, as that of the saw in its asce and descent. By means of wheel work the *velocity* of t moving body is increased or diminished at pleasure.

190. In short, machines enable us to form a convenient co munication between the power and the weight; to give to t weight any required direction or velocity; to apply force the best advantage; to vary the circumstances of velocity a time as the amount of our force may require; and to bring our aid the great moving powers that exist in nature. C next object, therefore, will be to see by what particular metho these several purposes are accomplished.

Regulation of Machinery, and Contrivances for Modifyi Motion.

191. It is highly important to the successful operation any machine, that its motion should be regular and unifor Jolts and irregular movements waste the power, wear upon machine, and perform the work unevenly. The sources of regularity are various, but they are chiefly the three followi viz. variations in the power, variations in the weight or resi ance, and changes of velocity in parts of the machine its Thus in the steam engine, the fire may burn with more or l intensity, and produce corresponding quantities of the mov power; the load to be carried (as that of a steam boat) n be much greater at one time than at another, and be subj to sudden changes; and the motion of the piston, which c ries the machinery, ceases altogether at the highest and l est points, and would move a machine by *hitches*, or sepa impulses, were there no contrivance connected with it for ke ing up a uniform motion.

192. The kinds of apparatus employed to obviate these ficulties, and to secure uniform movements to machines, in general, called REGULATORS. Large machines or engi

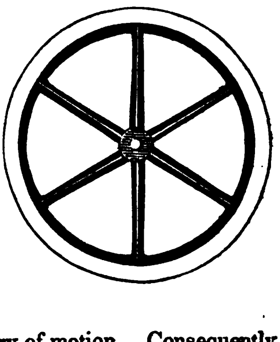
Enumerate the various purposes of machinery. What is essentia the successful operation of a machine? What are the three source *irregularity?* How exemplified in the steam engine? What gen *name is given* to the kinds of apparatus used to equalize motion?

themselves, in consequence of their inertia, acquire and maintain, to a considerable extent, uniformity of motion. A flour mill carried by water, when it has acquired a certain rate of going, will not suddenly change that rate by any alteration in the force of the stream; and a ship sailing between the opposite forces, arising from the impulse of the wind and the resistance of the water, will move steadily along, notwithstanding the breeze that carries it may fluctuate continually. We can see this principle sometimes operating on a smaller scale. A grindstone turned by a winch moves steadily, although the force applied at one part of the revolution is much greater than at another. Large grindstones exhibit the advantage of this principle much more than small ones. But in many instances, this natural tendency towards uniform motion is not sufficient, and artificial contrivances are introduced expressly for this purpose. As examples of Regulators we may especially notice two, the Pendulum, and the Fly Wheel.

193. The *Pendulum*, by its equal vibrations, communicates to delicate machinery a motion extremely regular, and hence its application to the measurement of time.

The *Fly Wheel* affords the most common and effectual method of equalizing motion, especially in heavy kinds of machinery. It consists of a heavy wheel (Fig. 54,) affording as much weight as possible under as small a surface, in order that the inertia may be great while the resistance from the air is small. It is therefore usually a heavy hoop of iron, with thick bars of the same metal. The Fly is balanced on its axis, and so connected with the machinery as to turn rapidly around with it; and receiving a constant impulse from the moving power, it becomes a magazine or repository of motion. Consequently, by its inertia, it is ready to supply any deficiency of power that may arise from the sudden diminution of the moving force, or to check any sudden impulse which may result from

Fig. 54.



Why do not large machines so much require regulators? How is the pendulum employed to regulate motion? Give a description of the fly wheel, and explain its principle.

an accidental excess of that force. Suppose, for example, the handle of a pump to be connected with a water wheel, and to be carried by it. Here the power, namely, the water fall, is constant, while the weight is subject to continual alternations, amounting to a heavy load as the piston is ascending, but opposing scarcely any resistance while the piston is descending. The motion, therefore, would vary between nothing and a highly accelerated velocity, and the machinery would be subject to constant strains and jolts. A Fly prevents these alternations and renders the ascent and descent of the piston nearly uniform. In pile engines or stamping mills, a team of horses is sometimes employed to raise a heavy weight, which when at a certain elevation, is suddenly disengaged and falls with great force. As the disengagement is instantaneous, the horses would instantly tumble down were not their motion checked by some contrivance which should prevent the machinery from receiving any sudden increase of velocity. This purpose is completely answered by the Fly.

194. Beside the use of the Fly Wheel in regulating the action of machinery, it is employed for the purpose of *accumulating* successive exertions of a power so as to produce a much more forcible effect by their aggregation, than could possibly be done by their separate actions. If a small force be repeatedly applied in giving rotation to a Fly Wheel, and be continued until the wheel has acquired a very considerable velocity, such a quantity of force will be at length accumulated in its circumference, as to overcome resistance and produce effects utterly disproportionate to the immediate action of the original force. Thus it would be very easy in a few seconds, by the mere action of a man's arm, to impart to the circumference of a Fly Wheel, a force which would give an impulse to a musket ball equal to that which it receives from a full charge of powder.

195. The same principle explains the force with which a stone may be projected from a sling. The thong is swung several times around by the arm until a considerable portion of force is accumulated, and then it is projected with all the collected force. If a heavy leaden ball be attached to the end of a strong piece of cane or whalebone, it may easily be driven through a board: by taking the end of the rod remote from the

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How is the Fly Wheel used for accumulating motion? Explain the action of a sling. What velocity may be given to a leaden ball attached to the end of a rod?

ball in the hand, and striking the board a smart blow with the end bearing the ball, such a velocity may easily be given to the ball as will drive it through the board.

196. The astonishing effects of a Fly Wheel, as an accumulator of force, have led some into the error of supposing that such an apparatus *increases the actual force of a machine.* So far from this, since a Fly cannot act without friction and resistance from the air, a portion of the actual moving force must unavoidably be lost by the use of this appendage. In cases, however, where a Fly is properly adjusted and applied, this loss of power is inconsiderable, compared with the advantageous distribution of what remains. As an accumulator of force, a Fly can never have more force than has been applied to put it in motion. In this respect it is analogous to an elastic spring. In bending a spring, a gradual expenditure of power is necessary. On the recoil, this power is exerted in a much shorter time than that consumed in its production, but its total amount is not altered. In this way the Fly Wheel is used. Thus, in mills for rolling metal, the water wheel or other moving power is allowed for some time to act upon the Fly alone, no load being placed upon the machine. A force is thus gained which is sufficient to roll a large piece of metal, to which, without such means, the mill would be quite inadequate. In the same manner, a force may be gained by the arm of a man acting on a Fly for a few seconds, sufficient to impress an image on a piece of metal by an instantaneous stroke.

197. We have already explained the mode in which motion is communicated, and it velocity regulated, by *wheel work.* We proceed now to consider a few examples of the more special contrivances by which motion is modified to suit particular purposes, recommending it to the student of mechanics to make himself acquainted with other contrivances of the same nature, by the actual inspection of machinery, as opportunity may offer.

198. The motion required for a particular purpose may be *rectilinear*, as that of a carriage or bucket drawn out of a well; or *rotary*, as in ordinary wheel work; or *reciprocating*, as in a saw mill, or a pendulum.

The simplest mode of producing rectilinear motion, is by means of a rope or chain, instances of which are familiar to

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Does the Fly Wheel increase the actual force of a machine? What *loss of power does it occasion?* Specify the several kinds of motion, as *rectilinear, rotary, and reciprocating.*

every one. The simplest mode of *changing the direction*, is by means of pulleys ; but toothed wheels are also extensively employed for the same purpose. The connexion of one toothed wheel with another, is called *gearing*. When both wheels with their teeth are in the direction of the same plane, it is called *spur gearing* (Figs. 41, 2, and 3,) ; if the teeth, instead of being cut on the circumference in a direction parallel to the axis, are cut obliquely, so that if continued they would pass round the axis like a screw, it is called *spiral gearing* (Fig. 54.) ; and when wheels are not situated in the same or parallel planes, but form an angle with each other, the wheels themselves are sometimes shaped like frustums of cones, having their teeth cut obliquely, and converging toward the point where the apex of the cone would be situated, and it is then called *bevel gearing*. (Fig. 55.)

Fig. 54.

Fig, 55.

Fig. 56.

199. The *universal joint* consists of two shafts or arms, each terminating in a semicircle, and connected together by means of a cross upon which each semicircle is hinged. (Fig. 56.) When one shaft is turned, either to the right or left, the other shaft turns in the same direction.

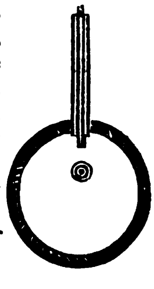
The *rachet wheel* (Fig.57.) is used to prevent motion in one direction while it permits it in the opposite. The teeth are cut with their faces inclining as in the figure, and a *catch* is so placed as to stop the wheel in one direction, while it slides over the teeth without obstruction in the opposite direction.

Fig. 57.

What is the simplest mode of producing rectilinear motion? Ditto of changing the direction? What is gearing? What is spur gearing? What is spiral gearing? What is bevel gearing? Explain the universal joint. Describe the ratchet wheel.

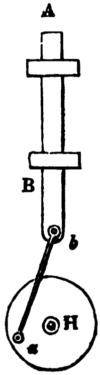
200. The *eccentric wheel* (Fig. 58.) revolves about an axis which is more or less removed from the center, and, consequently, the different portions of the circumference move with different degrees of velocity. Hence, if this wheel is made to act upon a shaft or pinion, as in the figure, it will carry it with a corresponding movement. In orreries, such wheels are employed for indicating the variable velocities of the heavenly bodies, as they revolve about their centers of motion.

Fig. 58.



201. Reciprocating Motion is produced in various ways. The most common method is by means of the *crank*. In Fig. 59, a shaft AB is urged backwards or forwards, (either vertically or horizontally,) by means of the crank *ab*, moving on a wheel H, which may be turned by water or any other power acting at H. By considering the different positions of the crank during the revolution of the wheel, it will be readily seen that the shaft will move up and down like the saw in a saw mill, or backwards and forwards, a use to which it is applied in polishing plane surfaces, as marble.

Fig. 59.



The motion produced by cranks is easy and gradual, being most rapid in the middle of the stroke, and gradually retarded towards the extremes; so that shocks and jolts in the moving machinery are diminished, or wholly prevented by their use.

202. The steam engine, as seen in steam boats, furnishes to the student of Mechanics a valuable opportunity of observing various contrivances for producing, regulating, and modifying motion. Levers and wheels of various kinds and variously connected; fly wheels and cranks; circular and reciprocating motions; and numerous other particulars which appertain to the "elements of machinery," are there seen to the greatest advantage.

Describe the eccentric wheel. How is reciprocating motion produced? Describe the crank. Explain the sort of motion produced by the crank. Specify the use of the steam engine in studying the modes of regulating and modifying motion.

CHAPTER XII.

OF THE PENDULUM, OF STRENGTH OF MATERIAI AND OF FRICTION.

The Pendulum.

203. The practical application of the Pendulum to t most important objects, namely, the measurement of time, estimation of the figure of the earth, and as a standard of wei and measures, renders it peculiarly deserving of the attenti the student of Natural Philosophy.

204. *A Pendulum is a body suspended by a right line any point, and moving freely about that point as a center.* point about which the pendulum revolves, is called the *ce of suspension.* The *vibration* of a pendulum, is its mo from a state of rest at the hightest point on one side, to the hightest point on the other side. The *center of oscillation* of a pendulum, is such a point that, were all the matter of the pendulum collected in it, the quantity of motion (or momentum) would be equal to the sum of the momenta of all the parts taken separately. Thus, the parts of the pendulum about b, (Fig. 60.) move faster than those about a, and consequently have more momentum ; but there is a point about which the momenta balance each other, and therefore, in the investigations relating to the pendulum, all the parts of which it consists may be considered as concentrated in that point.

Fig. 60.

The center of oscillation is below the center of gravity ; for since the parts more remote from the center of suspension have more *velocity* than parts that are nearer to it, the *quantity of matter* below the ce of oscillation must be less than the quantity of matter above

205. The doctrine of the Pendulum is mainly comprise the following propositions.

Define the pendulum. What are its three most inportant applicati Define the center of suspension—the vibrations of a pendulum—an *center of oscillation.* How is the center of oscillation situated wit spect to the center of gravity?

A pendulum of given length performs its vibrations in equal *nes, whether it vibrates in longer or shorter arcs.*

Upon this property of the pendulum, depends its application the measurement of time, as explained in Art. 152.

206. *The times of vibration of pendulums of different lengths,* *e proportioned to the square roots of their lengths.*

Thus, a pendulum, in order to vibrate half seconds, is only one urth as long as one that vibrates seconds, for
1 (the time of the longer) : $\frac{1}{2}$ (time of the shorter) : : $\sqrt{1}$: $\sqrt{\frac{1}{4}}$.
What must be the length of a pendulum to vibrate quarter conds?
Ans. It must be $\frac{1}{16}$ the length of the seconds pendulum, the uare root of $\frac{1}{16}$ being $\frac{1}{4}$ of 1; and since the length of a pendu- m beating seconds is about 39 inches, that of a pendulum ating quarter seconds is $\frac{39}{16}=2.44$ nearly.
Ex. 3. What would be the length of a pendulum that should orate once in an hour, the length of the seconds pendulum be- g $39\frac{1}{10}$ inches?
Ans. 7997.7 miles, equal to the diameter of the earth, nearly

207. *The times of vibration of the same pendulum on different* *rts of the earth's surface, are proportioned to the distances of these* *ints from the center of the earth.*

Hence, the pendulum affords the means of *measuring the ights of mountains*, and even of ascertaining the figure of the rth itself. For, since the times of vibrations are as the re- ective distances from the center of the earth, and since the nger the time occupied in one vibration, the smaller the number vibrations in an hour, consequently, the number of vibrations an hour at the level of the sea would be to the number on the p of a mountain, as the distance of this last point from the nter of the earth, to the distance of the general level from the nter.
For example, a pendulum which vibrated seconds at the level the sea, was found to vibrate only 3590 times on the top of a gh mountain; what was the height of the mountain?
Ans. 3590 : 3600 : : 3956* : 3,960, or nearly 4 miles.

How are the times of vibrations of a pendulum of given length? Do. of ndulums of different lengths? How much shorter is a pendulum vibra- ng quarter seconds, than vibrating seconds? What is the length of a ndulum that would vibrate once an hour? How are the times of vibra- n of the same pendulum, on different parts of the earth?

*The diameter of the earth is 7912 miles.

208. Again, the pendulum affords us the means of ascertaining *the figure of the earth;* for by counting the number of vibrations performed at various places on the earth's surface, (at the level of the sea,) we determine the ratio of the respective distances of those points from the centre of the earth. Now, if these distances should be all equal to each other, then the earth would be found to be a perfect sphere; but it is found by actual experiment, that the number of vibrations increases as we advance from the equator towards the poles, indicating that the polar diameter is less than the equatorial.

Example. If a pendulum which beats seconds at the equator, should be found to vibrate 3613 times in an hour at the pole, how much less is the polar than the equatorial diameter?

$$3613 : 3600 :: 4000 : 3985\tfrac{6}{10}.$$

This result being subtracted from 4000, (the equatorial radius,) leaves $14\frac{4}{10}$ miles, which, being doubled, gives $28\frac{8}{10}$ miles, as the difference between the polar and equatorial diameters.

209. The fact that at any given place, a pendulum which vibrates seconds, or which makes 3600 vibrations in an hour, is necessarily of the same length at all times, has led several nations to adopt this as *the standard of linear measure.* The square of this will serve as a standard for superficial, and its cube as a standard for solid measure.

Strength of Materials.

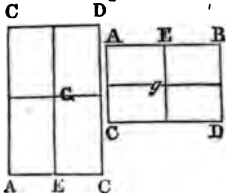
210. The importance to the architect and the engineer, of ascertaining the form and position of the materials which he employs, in order to secure the greatest degree of strength and stability, at the least expense, has led mathematicians and writers on mechanics, to devote much attention to this subject. How is the strength of a beam affected by giving to it different shapes and different positions; how must a given quantity of matter be disposed of in order that it may have the greatest possible degree of strength; and upon what principles depends the stability of columns, roofs, and arches; these, and many similar inquiries, have been objects of profound investigation.

211. The power of a regular beam, like a stick of timber, to resist fracture when supported horizontally at the two ends, is

Explain how the pendulum is applied to measure the height of mountains? also of ascertaining the figure of the earth? Upon what principle is the pendulum adopted as the standard of linear measures? *Strength of Materials.* Why has this subject been studied? What inquiries does it suggest?

tioned *to the depth of the center of gravity below the upper e.* Hence, an oblong beam is much stronger with its nar-ıan with its broad side upwards, l be seen by inspecting Fig. 61 ; ; center of gravity being here the of the stick, its depth EG is greater he narrow side is uppermost, than ; depth, when the beam rests on its ide. Thus, if a joist be 10 inches ınd 2½ thick, it will bear four times veight when laid on its edge, than aid flat-wise. Hence the modern mode of flooring with ıin, but deep pieces of timber.

Fig. 61.



iangular beam is twice as strong when resting on its broad ıs when resting on its edge. For the center of gravity ⅓ the distance from the vertex to the base, its depth is ıs great when the beam rests on its base as when it rests edge. This result of theory, however, has not been con- by experiment, but it appears to make no difference in the of a triangular beam, whether it rest on its broad base or edge. (Renwick's Mech. page 178.) These principles not only to beams, but to bars, and similar structures of sort of matter.

. *The strength of any bar in the direction of its length is tional to the area of its transverse section.*

number of cords were hanging side by side from the same ı the ceiling, they would be competent to sustain a weight h greater than a single cord would sustain, as their num- s greater than unity. Fifty cords, all bearing equally, obviously bear fifty times as great a weight without break- a single cord would do. Nor would their power be by being placed closely in contact with each other so as ıtitute one and the same cord. If, in the place of one of trings, we suppose rows or particles of any kind of matter, ength of the whole would be in proportion to their num- d this would be measured by the area of a cross section.

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hat is the strength of a stick of timber, placed horizontally, and on its two ends, proportioned? What side of an oblong beam e uppermost? Explain figure 61. How much stronger is a tri- beam on its broad base than on its narrow base? To what is ıgth of any bar in the direction of its length proportioned? State *nple of a number of cords* suspended from the ceiling and support- *hts.*

Hence, the various shapes of bars makes no difference in their absolute strength, since this depends only on the area of the section, and must obviously be the same when the area is the same, whatever be the figure. A rope, therefore, or a wire, to which a weight is appended, is as likely to break in one place as in another; but when the weight of the rope becomes considerable, and the force is applied perpendicularly, the increase of weight as its length increases, renders it more liable to break in the upper than in the lower parts.

213. *The strength of a beam lying horizontally is inversely as its length.*

Hence, a beam twice as long as another equal to it in all other respects, has only half the strength. Long beams are weak from their own weight; and the length may be so increased, that they will break from this cause alone.

214. *The tendency to fracture on any part of a horizontal beam supported at both ends, is proportional to the product of the distances of that part from the supported ends.*

In a common stick of timber, therefore, resting horizontally like the joists of a floor, the liability to break is greatest in the middle, and decreases both ways to the ends; for the product of the two halves is the greatest that can result from any two parts, and the more unequal the parts are, the less is the product. Hence, a beam, in order to be equally strong throughout, must be made tapering, being largest in the center, and growing less and less towards the ends. Exact calculation shows, that the true figure of such a beam is that whose section is an ellipse.

The timbers which compose the horizontal part of the frame of a house, being usually rectangular parallelopipeds of uniform dimensions throughout, it is manifest that a considerable portion of the material is wasted; but in such cases, the attempt to save the material would be attended with paramount disadvantages. When, however, the material is expensive, or where lightness is important, as in many kinds of machinery, the foregoing principle may be applied with great advantage. A useful application

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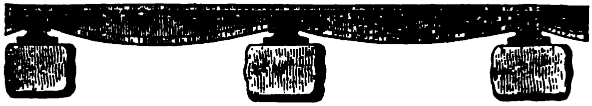
Is a rope or wire more liable to break in one place than another? How is the strength of a horizontal beam proportioned to its length? Why are long beams weak? To what is the tendency of a horizontal beam to break at different points, proportioned? What must be the shape of a beam to be equally strong throughout? Are beams of this shape used in houses? In what cases are they employed?

of it is seen in the shape given to the iron bars of railways, as represented in the following figure.

Fig. 62.



215. On the foregoing principles, Dr. Gregory makes the following remarks, most of which were originally suggested by Galileo, to whom we are indebted for the earliest investigation of these propositions. From the preceding deduction (says Gregory) it follows, that longer beams and bars must be in greater danger of breaking than less similar ones; and that, though a less beam may be firm and secure, yet a greater similar one may be so long as necessarily to break by its own weight. Hence, Galileo justly concludes, that what appears very firm, and succeeds well, in models, may be very weak and unstable, or even fall to peices by its weight, when it comes to be executed in large dimensions, according to the model. From the same principles he argues, that there are necessarily limits in the works of nature and art, which they cannot surpass in magnitude; that immensely great ships, palaces, temples, &c., cannot be erected, since their yards, beams, bolts, and other parts of their frame, would fall asunder by their own weight. Were trees of a very enormous magnitude, their branches would, in like manner, fall off. Large animals have not strength in proportion to their size; and if there were any land animals much larger than those we know, they could hardly move, and would be perpetually subjected to the most dangerous accidents. As to marine animals, indeed, the case is different, as the specific gravity of the water sustains those animals in a great measure; and in fact these are known to be sometimes vastly larger than the greatest land animals.* It is (says Galileo) impossible for Nature to give bones to men, horses, or other animals, so formed as to subsist, and proportionally to perform their offices, when such animals should be enlarged to immense heights, unless she uses matter much

Which are most liable to break, long beams or short ones? Are structures stronger or weaker, proportionally, than their small models? What would be the consequence were trees much larger than they are? State the case of large land animals and of marine animals.

*Whales in the *Northern Regions*, are sometimes found sixty feet long, and weighing *seventy tons.*

firmer and more resisting than she commonly does; or should make bones of a thickness out of all proportion; whence the appearance and figure of the animal must be monstrous. Hence we naturally join the idea of greater strength and force with the grosser proportions, and that of agility with the more delicate ones. The same admirable philosopher, likewise remarks, in connexion with this subject, that a greater column is in much more danger of being broken by a fall than a similar small one; that a man is in greater danger from accidents than a child; that an insect can sustain a weight many times greater than itself, whereas, a much larger animal, as a horse, could scarcely carry another horse of his own size.

216. *The lateral strengths of two cylinders, of the same matter, and of equal weight and length, one of which is hollow and the other solid, are to each other as the diameters of their sections.*

The strongest form, therefore, in which a given quantity of matter can be disposed, is that of a hollow cylinder. From this proposition Galileo justly concludes, that Nature in a thousand operations greatly augments the strength of substances without increasing their weight; as is manifested in the bones of animals, and the feathers of birds, as well as in most tubes or hollow trunks, which, though light, greatly resist any effort to bend them. Thus, (says he,) if a wheat straw, which supports an ear that is heavier than the whole stalk, were made of the same quantity of matter, but solid, it would bend or break with far greater ease than it now does. And with the same reason, art has observed, and experience confirmed the fact, that a hollow cane, or tube of wood or metal, is much stronger or firmer, than if, while it continues of the same weight and length, it were solid; as it would then, of consequence, be not so thick. For the same reason, lances, when they are required to be both light and strong, are made hollow.

Friction.

217. The term Friction, in its usual acceptation, being generally understood, we have already employed it in the foregoing pages; but we now proceed to inquire more particularly res-

State the comparative liability of a man and a child to receive injury from falling—strength of insects. What is the strongest form in which a given quantity of matter can be disposed? Examples of such forms in nature and art.

pecting its nature, the laws of its action, and its effects upon machines.

In investigating the mathematical principles of mechanics, we first proceed on the supposition that the forces in question act without any impediments; that the surfaces which move in contact are perfectly polished and suffer no friction; that axes and pivots are mathematical lines and points; that ropes are perfectly flexible; and, in short, that the power is transmitted through the machine to the working point without sustaining the least loss or diminution. Great simplicity is attained by first bringing the subject to this ideal standard of perfection, and afterwards making suitable allowances for all those causes which operate in any given case to prevent the perfect action of a machine.

218. Surfaces meet with a certain degree of resistance in moving on each other, in consequence of *the mutual cohesion of the parts;* a principle which has the greater influence in any given case, in proportion as the surfaces are smooth. But a much greater resistance arises from the asperities which the surfaces of all bodies have, though in very different degrees, according to their different degrees of smoothness. An extreme case is that of two brushes moving on each other, the hairs of which become interlaced, (especially when the brushes are pressed together,) and oppose a great resistance. Even bodies apparently very smooth, as polished metals, exhibit under the microscope numerous inequalities. Under the solar microscrope, the finest needle exhibits a surface as rough as the coarsest iron tools do when viewed by the naked eye. To these inequalities of surface, is principally ascribed the friction of bodies, when closely in contact; the prominent parts interlock with one another, or meet, and must be broken down before the surfaces can move. Hence, friction is diminished by processes which level these inequalities, either by polishing the surface, or by smearing it with some lubricating substance which fills up the cavities.

219. Forces of this nature, which act by the resistance they occasion to motion, are called *passive* forces. They produce very different effects in machines when in a state of equi-

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Friction.—In the mathematical theory of mechanics, is any allowance made for friction or other impediments? Why are these at first neglected? What are the sources of friction? What is there in the nature of the surfaces of bodies which occasions friction? How is friction *diminished? What are passive forces?*

librium, and in a state of motion. In the one case they assist the power; in the other case they oppose it. Thus, a weight placed on an inclined plane, will require a less power to *support* it in consequence of the friction of the plane; and a weight suspended by a rope passing over a pulley will require a less weight to *balance* it, on account of the friction of the axle. But the same passive forces operate in just the contrary way when a machine is to be put in motion; for then a power must be applied, which is sufficient not only to overcome the weight itself, but also the amount of all the resistances. For example, in order to draw a load up an inclined plane, we have to overcome not only the force of gravity by which the load endeavors to descend down the plane, but also the amount of the friction and all the other resistances which impede its motion, although the load would be kept from *descending*, that is, in a state of equilibrium, by a less force in consequence of these resistances. The principle is most strikingly observed in the wedge, where the difficulty of making the wedge *advance*, is greatly increased by friction, but the same cause operates to prevent it from *recoiling*.

220. The forms under which this sort of resistance presents itself, are chiefly of two kinds, namely, that of bodies *sliding*, and of bodies *rolling* on each other. To the former of these let us first attend. Experiments on the friction of sliding bodies may be made, either by placing them on a table, and observing the weights which they respectively require to drag them along the table, or by placing them on an inclined plane, and observing at what angle the plane must be elevated in order that the body may *begin* to slide. In the former case, the table is prepared by attaching a vertical pulley to one edge, over which a string is passed, one end being connected to the body in question, and the other end to a pan, like that of a balance, for containing weights. From this simple arrangement, a great variety of particulars may be ascertained respecting the friction of sliding surfaces. A body shaped like a brick, with a broader and a narrower side, may be tried on each of its sides separately, and thus it may be seen whether, in a given weight, the *extent of surface of contact* makes any difference; the body may be loaded with different weights, and hence may be learned the *influence of pressure* upon friction; the body may be tried

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In what case do they assist the power? In what case do they oppose *it? How exemplified in the wedge?* How are experiments on *sliding bodies made?* Describe the arrangement with a table and balance.

as soon as it is laid on the table, and after remaining on it for a longer or shorter time, in order to learn whether this circumstance alters the friction; different kinds of bodies may be tried, and the influence of different materials ascertained; and finally, by dragging the body off the table with different degrees of velocity, the relation of friction to velocity may be investigated.

221. From experiments like the foregoing, endlessly varied, the following conclusions have been established:

(1.) In a given body, *extent of surface* makes no difference in regard to friction; a brick laid on its edge meets with the same resistance from this cause as when laid on its side.

(2.) Friction is proportioned to the *pressure.* If the pressure of the brick be doubled or trebled by laying weights upon it, the amount of friction will be increased in the same ratio.

(3.) Friction is increased by bodies *remaining for some time in contact with each other.* In some cases it does not reach its maximum under four or five days. This principle, therefore, affects slow motions much more than such as are rapid. In the mutual contact of metals, the friction attains its maximum almost instantaneously. But when metal rubs against wood, or one piece of wood against another, the friction is always increased by resting.

(4.) The friction is less between surfaces of *different* kinds of matter, than between those of the *same* kind. Copper slides on copper, or brass on brass with greater difficulty than copper on brass; and it is a general rule never to let two substances of the same hardness move upon each other. To this rule, cast steel is said to form the only exception; in other cases pivots revolve with less resistance on either harder or softer substances than upon those of the same material with themselves. When between the surfaces of wood neatly planed, the friction would be equal to one half the pressure; and when between two metallic surfaces, it would be equal to one fourth, between the wood and metal, it would amount to only one fifth the pressure.

(5.) Friction is much greater at the first moving of a load, than after it is brought freely into motion. In many instances,

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Does extent of surface make any difference? How is the friction related to the pressure? How affected by bodies remaining long in contact? How is the friction between bodies of *different* kinds? What substance forms an exception? Amount of pressure between wood and metal? *Amount of friction* at first moving a load—how much is it reduced when a body has reached its final velocity?

it is reduced, when a body has attained its final velocity, to less than one half of what it was at first. With regard to different degrees of velocity in moving bodies, it is a *general* principle, that *the friction is the same for all velocities*; that a carriage, for example, in travelling from one place to another, would encounter the same resistance from friction, whether it performed the journey in one hour or in ten. The amount of friction, however, is augmented in very slow motions, and greatly diminished in those that are very swift. In this instance, the increase in the one case and the diminution in the other, appears to have some relation to the principle, that the friction of bodies is increased by their remaining in contact. From some observations of Professor Playfair, made at the slide of Alpnach, where large fir trees are carried with great velocity down an inclined plane eight miles in length, it would appear, that in the case of very great velocities, friction is not, according to the common doctrine, either proportioned to the pressure or independent of the velocity; but that the ratio to the pressure is greatly diminished, and the actual resistance is far less than at common velocities. Thus, none but large trees could descend the plane at all; and when a tree broke into two pieces, the larger part would proceed while the smaller would stop; and the trees acquired in their descent a rapidity of motion, incompatible with the supposition that "friction acts as a uniformly retarding force," which has been considered as an established principle.

The foregoing considerations are in favor of rapid travelling, whether on common roads or on railways, since the amount of the resistances is so much less than in slow movements; and accordingly it is said, that the great speed given to stage coaches in England, amounting in some instances to ten or twelve miles per hour, has not been attended with the degree of exhaustion to the teams that would have been anticipated.

222. The laws of friction in *rolling* bodies are ascertained by comparing the forces necessary to roll a cylinder upon a table under various circumstances; and by similar experiments are found the modes in which friction takes place in bodies *revolving* on an axis. The comparative loss of power which takes place in these three cases, is as follows:

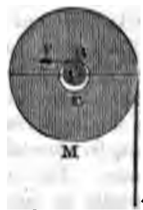
When a body moves over the same space with different velocities, how is the friction? Relate the facts observed at the Slide of Alpnach. Do the doctrines of friction favor slow or rapid travelling? How are the *laws of friction* in *rolling* bodies investigated?

on of the sliding body is equal to ¼ the pressure or 25

on of the revolving body - - - - 15 per cent.
rolling do. - - - - - - 5

case of hollow cylinders revolving on an axis, the *lev-* the wheel aids in overcoming friction. Let. Fig. 63, t a section of the wheel and axle. Let : center of the axle, and let BE be the cylinder in the nave of the wheel 1 the axle is inserted. If B be the which the axle presses, and the wheel he direction NDM, the friction will in the direction BF, and with the lev- C. The power acts against this at direction DA, and with the leverage is therefore evident, that as DC is than BC, in the same proportion does the power act chanical advantage over the friction. On this princi- nportant advantage is sometimes gained in machines by *ing* the friction from one point to another, as from the rence to the axis of a pulley.

Fig. 63.



Friction Wheels, a contrivance by which friction is di- l in the greatest degree possible, owe their efficacy in ne operation of the same principle. Here the axis of instead of revolving in a hollow cylinder, or instead of against a fixed surface, rests, at each of its extremities, rcumference of two wheels placed close by the side of er, with their circumferences intersecting. The axis the point of intersection, and as it revolves, the wheels vith it with the same velocity, and thus all friction be- em and the axis is prevented, and what remans in the in consequence of the weight of the wheels themselves, *erred* to their axles, and therefore is diminished, in the he diameter of one of the wheels to that of its axis. nbination may be repeated by several pairs of friction Eight wheels would contract the friction to the thou- rt.

Other more common methods of diminishing friction endering the surfaces smooth, by using rollers, and by

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s the comparative amount of friction in sliding, revolving, and lies? In wheel carriages, how does the leverage of the wheels friction? What is the construction of friction wheels? How *ld eight friction wheels* diminish the friction?

lubricating the parts in contact. The amount of friction in the several mechanical powers is very different. In the Lever it is very small, especially when the turning edge is of hardened steel and shaped like a knife or prism, and turns upon a hard and smooth basis. The Wheel and Axle, acting upon the same principle as the Lever, occasion but little friction. The stiffness of the cordage, however, and the friction of the gudgeons of the axis have an effect in most cases equal to about 8 or 10 per cent. of the entire resistance. The Pulley is attended with great loss from this source. It is rarely less than 20 per cent. and often exceeds 60. The Inclined Plane involves but little friction when bodies simply roll on it; but when heavy bodies rest on axes, as in wheel carriages, the resistance from friction takes place in the same manner as upon plane surfaces. The transportation on inclined planes, as railways, is usually by means of wheels, since the resistance to sliding movements is too great to permit the use of them. The Screw is attended with a great deal of friction. Those with sharp threads have more than those with square threads, and the endless screw has most of all. In both the Screw and the Wedge, the friction evidently exceeds the resistance; otherwise they would not retain their position.

225. Friction is not, therefore, in all cases to be considered as unfavorable to the operation of machinery. It is, in many instances, a highly useful force. Many structures, as those of brick and stone, owe no small part of their stability to the roughness of the materials of which they are composed; without this resistance, the screw and the wedge would lose their efficacy, and the wheels could not advance, nor could animals walk on the ground; and nails would lose their power of binding separate parts together. The art of polishing surfaces depends on the same cause, and the edges of most cutting instruments are saws, the teeth of which are more or less fine, and act on a similar principle. Even in certain rotary motions, friction becomes a moving force and urges a body in particular directions contrary to the force of gravity.

What are the methods of diminishing friction? Specify the comparative amount of friction in the lever, the wheel and axle, the pulley, the inclined plane, the screw, and the wedge. Is the friction always to be considered as a loss? Specify its uses.

PART II.—HYDROSTATICS.

CHAPTER I.

OF FLUIDS AT REST.

226. THE principles of Mechanics, demonstrated and explained in the foregoing pages, are *universal* in their application, extending alike to all bodies, whether solid or fluid. But in addition to those properties which fluids have in common with solids, and which bring them under the general laws of Mechanics, they have also properties peculiar to themselves, which give rise to a distinct class of mechanical principles, not applicable to solid bodies. These are embraced under the heads of HYDROSTATICS and PNEUMATICS, the former division comprising the doctrine of liquids, and the latter that of aeriform bodies or gases.

227. *A* FLUID *is a body whose particles move easily among themselves, and yield to the least force impressed; and which, when that force is removed, recovers its previous state.*

Since water, wind, and steam, are the only fluids that are usually employed as mechanical agents, the doctrines of Hydrostatics and Pneumatics, have regard chiefly to them; but the principles established respecting these, are applicable also to all analogous bodies.

It has been usual to denominate liquids and gases respectively *elastic* and *non-elastic* fluids, on the supposition that water and other liquids are nearly or quite incompressible. An experiment performed by the Florentine academicians, as long ago as 1650, seemed to prove that water is wholly incompressible. They filled a hollow ball of gold with water, and subjected it to a strong pressure. The water, not yielding to the compression, oozed through the pores of the gold. Considering the great density and compactness of this metal, the experiment

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HYDROSTATICS.—To what bodies do the principles of Mechanics apply? What is said of the *peculiar* properties of fluids? To what new heads do these properties give rise? Define a fluid. What fluids are employed as mechanical agents? Are liquids elastic or non-elastic? *Mention the experiments of* the Florentine academicians.

was for a long time held as proving decisively that water is wholly incompressible. Although this experiment shows that water is compressed with great difficulty, yet later experiments have proved, that it is still capable of compression. The most decisive evidence of this point has been recently afforded by the experiments of Mr. Perkins. It had been previously ascertained, that by a pressure equivalent to that of the atmosphere, or about fifteen pounds to the square inch, water is compressed about one part in twenty-two thousand. Mr. Perkins, by methods to be described hereafter, applied successive degrees of pressure up to that of two thousand atmospheres, and found the contraction of volume to increase nearly in the ratio of the compressing force.

228. HYDROSTATICS *is that branch of Natural Philosophy which treats of the mechanical properties and agencies of* LIQUIDS.

229. *Fluids at rest press equally in all directions.*

A point in a mass of fluid, taken at any depth, exerts and sustains the same pressure in all directions, upwards, downwards, or laterally. This is the most remarkable property of fluids, and is what particularly distinguishes them from solids, which press only downwards, or in the direction of gravity. This property naturally results from the freedom of motion that subsists between the particles of fluids; for if, when a fluid is at rest, the pressure on any given portion were not equal in all directions, that portion would move in the direction in which the resistance was least. But by the supposition it does not move: therefore it is kept at rest by equal and contrary forces acting on all sides. But the most satisfactory evidence of this truth is obtained from experiment. On opening an orifice in the side of a vessel of water, and estimating the force with which the water issues, it is found to be equal to the weight of the incumbent fluid; and the upward pressure of water at a certain depth is found to sustain the heaviest bodies when exposed to its action alone, the column above the bodies, and of course the downward pressure, being removed.

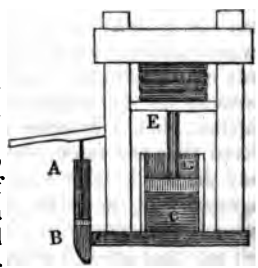
Mention the experiments of Mr. Perkins. What was the result? Define Hydrostatics. What is the law of pressure of fluids at rest? What is the distinguishing property of fluids? From what property of fluids does this equality of pressure result? What experiment proves it?

230. ***A given pressure or blow impressed on any portion of a mass of water confined in a vessel, is distributed equally through all parts of the mass.***

A given pressure, as that made by a plug forced inwards upon a square inch of the surface of a fluid confined in a vessel, is suddenly communicated to every square inch of the vessel's surface, however large, and to every inch of the surface of any body immersed in it. Thus, if I attempt to force a cork into a vessel full of water, the pressure will be felt, not merely by the portion of the water directly in the range of the cork, but by all parts of the mass alike; and the liability of the bottle to break, supposing it to be of uniform strength throughout, will be as great in one place as another; and a bottle will break at the point where it happens to be weakest, however that point may be situated relatively to the place where the cork is applied; and the effect will be the same whether the stopper be inserted at the top, the bottom, or the side of the vessel.

231. It is this principle which operates with such astonishing effect in the *Hydrostatic Press*, by means of which a single man can exert a force equal at least to 25000 lbs. and adequate to crush the hardest substances, or cut in two the largest bars of iron. Its construction is as follows. Fig. 64 represents a press made of the strongest timbers, the foundation of which is commonly laid in solid masonry. AB is a small cylider in which moves the piston of a forcing pump; and CD is a large cylinder in which also moves a piston, having the upper end of its rod pressing against a movable plank E, between which and the large beam above, is placed the substance to be subjected to pressure, as for example a pile of new bound books. By the action of the pump handle, water is raised into the small cylinder, and, on depressing the piston, it is forced through a valve at B into the larger cylinder, and raises the piston D, which expends its whole force on the bodies confined at E. Now, since whatever force is applied to any one portion of the fluid, extends alike to every part, therefore the

Fig. 64.



How is a pressure or blow on any part of a confined mass of fluid distributed? Give examples. Hydrostatic Press—describe it from figure 64.

force which is exerted by the pump upon the smaller column, is transmitted unimpaired to every inch of the larger column, and tends to raise the movable plank E with a force as much greater, in the aggregate, than that impressed upon the surface of the smaller, as this surface is smaller than that of the larger column; or (which is the same thing) as the number of square inches in the end of the piston B is less than that of the piston D. The power of such a machine is enormously great; for, supposing the hand to be applied at the end of the handle, with a force of only ten pounds, and that this handle or lever is so constructed as to multiply that force but five times, the force with which the smaller piston will descend will be equal to 50 lbs.; and let us suppose that the head of the larger piston contains the smaller 50 times, then the force exerted to raise the press board, will equal 2500 lbs. A man can indeed easily exert ten times the force supposed, and can therefore exert a force upon the substance under pressure equal to 25000 lbs.

232. The rationale of the principle of the Hydrostatic Press, will be best understood by recurring to the doctrine of *Virtual Velocities*. It will be recollected that opposite forces are in equilibrium when their *momenta* are equal; that a small power may be made to balance a great weight, by making it move, in a given time, over a space as much greater than the larger does, as its weight is smaller; and that it may be made to overcome that resistance or weight, and give motion to it, if its velocity is greater than that of the latter in a still higher ratio. Now to apply these principles to the case before us, it is evident that any quantity of water forced out of the smaller into the larger cylinder, must rise in the latter as much slower as the area of the horizontal section is larger. If, for example, the capacity of the larger cylinder were ten times that of the smaller, then a quantity of water one inch in height, transferred from the smaller to the greater cylinder, would occupy only the height of one tenth of an inch, and consequently the depression of the small piston one inch would raise the large one only the tenth of an inch. This case, therefore, resolves itself into that general principle, according to which a vast force is exerted through a short distance, by moving a small force through a distance much greater. The exertion of a power-

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Show how the whole force communicated to the smaller column is transmitted to the larger. What amount of force can a man exert with *his naked* hands? Explain the *principle* of the Hydrostatic Press? *Through how much* less space does the fluid rise in the larger than in the *smaller tube?*

Hence it appears that at the moderate depth of 64 feet, the pressure of a column of water on the bottom or sides of the containing pipe, becomes 4000 lbs to the square foot; and the pressure on the bottom of the sea, where it is one mile in depth, is 330,000 lbs. to the square foot, and where it is five miles deep, that pressure is no less than 1,650,000 lbs.* From these considerations we may readily apprehend the cause of the great difficulty experienced in confining a high column of water; and hence also may be inferred the immense pressure that is exerted on the bottom of the sea.

237. Indications of this vast pressure in deep waters, are manifested by several interesting facts. It has long been known to mariners, that if a common square bottle be let down into the sea, its sides are crushed inwards before it has reached the depth of ten fathom. If a stronger bottle, (a common junk bottle, for example,) be filled with water, corked close, and let down to a certain depth, either the cork will be forced inwards, or if that is secured in its place, the salt water will make its way into the bottle in spite of it, either by compressing the cork, or by forcing in water through it. It was by sinking an apparatus to the depth of 500 fathoms, that Mr. Perkins first proved the compressibility of water, as mentioned in Art. 227. The apparatus consisted of a hollow brass cylinder, resembling a small cannon, and furnished with a stopper so contrived as to indicate, when the apparatus was drawn up, how far it had been driven in while at the lowest depth. The same experiments were afterwards repeated on shore, a pressure being applied to the plug, by means of the hydrostatic press, equivalent to 2000 atmospheres.

The increase of pressure in proportion to the depth of the fluid, renders it necessary to make the sides of pipes or masonry, in which fluids are to be contained, stronger the deeper they go. The same remark applies to dams, flood-gates, and banks.

238. At the depth of 1000 fathoms, the compression of water is *one twentieth* of its bulk, and its specific gravity is increased in the same ratio; so that bodies which sink near the surface of the sea, may float at a certain depth before they

State examples of indications of this vast pressure at different depths. Case of a junk bottle—experiments of Mr. Perkins. How great a pressure did Perkins apply by means of the hydrostatic press? In what parts do cisterns require to be made strongest? What is the compression of water at the *depth of 1000* fathoms?

* *Allowance must always be made for the saltness of the sea, salt water being heavier than fresh.*

reach the botton. On the other hand, a porous body, that is light enough to float near the surface, will have so much water forced into its pores, when it is sunk to a great depth, as never to rise. This is the case with ships that are wrecked in deep water; the parts of the wreck do not rise to the surface, as they do in shallow water.

239. When a portion, as a square foot, of the lateral surface of a column of water, is taken, all parts of it are not equally distant from the surface of the fluid; and, in this case, the *average* depth, or (which is the same thing) the depth of the *center of gravity*, is to be understood according to the following proposition, which applies to every sort of surface, however inclined to the horizon.

The pressure of a fluid against any surface, in a direction perpendicular to it, varies as the area of the surface multiplied into the depth of its center of gravity below the surface of the fluid.

Hence, the pressure on the side of the cubical vessel, filled with fluid, is one half the pressure against the bottom; and the whole pressure against the sides and bottom, is equal to three times the weight of the fluid of the vessel.

Fig. 66.

240. *Fluids rise to the same level in the opposite arms of a recurved tube.*

Let ABC, (Fig. 66,) be a recurved tube: if water be poured into one arm of the tube, it will rise to the same height in the other arm. For, by Art. 235, the pressure upon the lowest part at B, in opposite directions, is proportioned to its depth below the surface of the fluid. Therefore, these depths must be equal; that is, the heights of the two columns must be equal, in order that the fluid at B may be at rest; and unless this part is at rest, the other parts of the column cannot be at rest. Moreover, since the equilibrium depends on nothing else than the

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Case of ships wrecked in deep water. In inclined and extended surfaces, how is the depth to be estimated? What is the pressure on the *side of a* cubical vessel filled with water? What is the whole pressure *on the sides* and bottom? To what heights do fluids rise in the opposite *arms of a* recurved tube?

ful force through a small space, is usually what is required in a press ; and since this force acts with far less loss by friction than the screw, it is proportionally more efficacious and economical.

233. *The surface of a fluid at rest is horizontal.*

The evidence of the truth of this proposition is threefold. *First*, this result is a natural consequence of the mobility of fluids, since, if any portion is raised above the rest, having nothing to support it, and being acted on by gravity, it must descend in the same manner as a body placed on a perfectly smooth inclined plane. *Secondly*, whenever a body is free to move, its *center of gravity* will descend as low as possible. When, therefore, any portion of a fluid is raised above the general level, the center of gravity of the mass is raised, and it must return before the fluid can be at rest. *Thirdly*, experience shows that the proposition is true, since fluids, when free to move, always settle themselves with their surfaces parallel to the horizon. It must be understood, however, that the surface of large bodies of water is not, strictly speaking, a horizontal level, but is a portion of the convex surface of the earth ; for since the center of gravity of every portion of the fluid will descend as low as possible, the whole will dispose itself around the center of attraction so as to form a portion of the earth's surface. For small distances the curvature is so slight that it may be neglected, not amounting to one second of a degree for 100 feet ; and for the distance of a mile, the deviation from a straight line, drawn in the direction of a tangent, is not more than 8 inches.

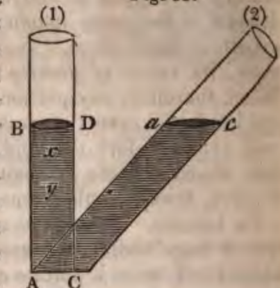
234. A practical application of this principle is made in the art of *levelling*. A level is sometimes made by merely cutting a groove or channel in a flat piece of board and filling it with water. When the board is brought into such a situation that the water in the groove remains stationary, the position is horizontal. But the *spirit level* is the instrument more commonly employed for this purpose. This consists of a small cylindrical tube of glass, from two to six inches long, filled with spirits of wine or ether, except a small space, which is occupied by a

Why is this force more efficacious and economical than the screw? How is the surface of a fluid at rest? What evidence have we that a fluid at rest is parallel to the horizon. Are the surfaces of large bodies of water horizontal planes? What is the actual figure of the surface? What is the deviation from a straight line in 100 feet? How much in a mile? On what is the art of levelling founded? Describe the water level—also the spirit level.

movable bubble of air. When such a tube is placed horizontally, the bubble of air will remain stationary in the center of the tube, at a fixed mark; but whenever the tube is inclined, in the least degree, the bubble will ascend towards the elevated end. Spirit levels are much used for adjusting astronomical, surveying, and other delicate instruments.

235. *The pressure upon any particle of a fluid of uniform density, is proportioned to its depth below the surface.*

Fig. 65.



Thus in Fig. 65, the pressure exerted by the fluid at different depths, as x and y, is found to be exactly proportioned to their depth below the surface, so that if y be twice as deep as x, a body at y would sustain twice as much pressure as at x. But since the inclined column AC *ac*, is of the same perpendicular height as the erect column ABCD, both exert the same pressure on the base AC.

236. According to Art. 229, the lateral is equal to the downward pressure; and consequently on this principle may easily be estimated the amount of pressure on the sides of any column of water, or on the banks of rivers, canals, &c. At the depth of 8 feet, the pressure on a square foot is equal to the weight of a column of water, whose base is 1 foot and depth 8 feet, and consequently its solid contents 8 cubic feet; and since 1 cubic foot of water weighs 1000 ounces, or $62\frac{1}{2}$ lbs. therefore the weight of the column$=8\times62\frac{1}{2}=500$ lbs. Hence the pressure on a square foot, at different depths, will be as in the following table.

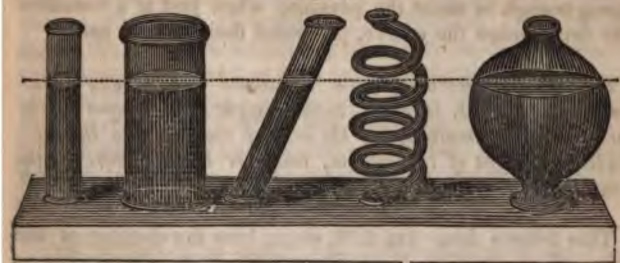
Depth in feet.	Pressure on a square foot.	Depth in feet.	Pressure on a square foot.
8	- - - - - 500 lbs.	56	- - - - - 3500 lbs.
16	- - - - - 1000	64	- - - - - 4000
24	- - - - - 1500	72	- - - - - 4500
32	- - - - - 2000	80	- - - - - 5000
40	- - - - - 2500	88	- - - - - 5500
48	- - - - - 3000	96	- - - - - 6000

1 mile, or 5280 feet, - - - 330,000 lbs.
5 " - - - - - - - - - 1,650,000

What is the pressure on a square foot at the depth of 8 feet in a column of water? State the pressure at several different depths, as at 32, 48, 56, and 80 feet. Also at the depth of 1 mile, and 5 miles.

heights of the respective columns, therefore, the opposite columns may differ to any degree in quantity, shape, or inclination to the horizon. Thus, if vessels and tubes very diverse in shape and capacity, as in Fig. 67, be connected with a common reser-

Fig. 67.



voir, and water be poured into any one of them, it will rise to the same level in them all.

The reason of this fact will be farther understood from the application of the principle of *Virtual Velocities*, (Art. 179.); for it will be seen that the velocity of the columns, when in motion, will be as much greater in the smaller than in the larger columns, as the quantity of matter is less; and hence the opposite momenta will be constantly equal.

241. Hence, water conveyed in aqueducts, or running in natural channels, will rise just as high as its source. Between the place where the water of an aqueduct is delivered and the spring, the ground may rise into hills and descend into valleys, and the pipes which convey the water may follow all the undulations of the country, and the water will run freely, provided no pipe is laid higher than the level of the spring. Waters running in natural channels in the earth are governed by the same law.

242. The aqueducts constructed by the ancient Romans, were among the most costly ornaments of their arts. Several of them were from thirty to one hundred miles in length, and consisted of vast covered canals, built of stone. They were carried over valleys and level tracts of country upon arcades, which were sometimes of stupendous height and solidity. From the fact that the ancients built aqueducts with so much labor, raising them to a great height in crossing valleys, instead of

Does the shape of the vessel make any difference? How is equality of the *height in vessels of* various figures to be explained? How high will *water rise in aqueducts?* Give an account of the aqueducts of the *ancient Romans.*

availing themselves of the principle under consideration, have supposed that they were unacquainted with this princ It appears, nevertheless, that they were acquainted with it even understood the use of pipes in conveying water; but bably the expense of pipes, and the difficulty of making strong enough to resist the pressure when laid at a cons able depth below the source, prevented their general use.

243. *The pressure upon the horizontal base of any containing a fluid, is equal to the weight of a column o fluid, found by multiplying the area of the base into the pendicular height of the column, whatever be the shape o vessel.*

This follows from Art. 239, since, here the distance o center of gravity from the surface of the fluid, is the san the perpendicular height of the column. With a given and height, therefore, the pressure is the same, whethe vessel is larger or smaller above, whether its figure is re or irregular, whether it rises to the given height in a l open funnel, or is carried up in a slender tube. Hence *quantity of water, however small, may be made to balance quantity, however great.* This is called the *hydrostatic paradox*. The experiment is usually performed by means of a water bellows, as is represented in Fig. 68. When the pipe AD is filled with water, the pressure upon the surface of the bellows, and consequently the force with which it raises the weights laid on it, will be equal to the weight of a cylinder of water, whose base is the surface of the bellows, and height that of the column AD.. Therefore, by making the tube small and the bellows large, the power of a given quantity of water, however small, may be increased indefinitely. The pressure of the column of water in this case corresponds to the force applied by the piston in the Hydrostatic Press, (Art. 231,) and the explanation according to the principles of virtual velocities, is the same in both cases.

Fig. 68.

Why did they not convey water in pipes? To what is the pressu the horizontal base of any vessel containing a fluid equal? What hydrostatic paradox? How is the experiment performed? Desc apparatus.

244. The principle of the Hydrostatic Paradox, is sometimes xemplified in pouring liquids into casks, through long tubes nserted in the bung holes. As soon as the cask is full, and the vater rises in the pipe to a certain height, the cask bursts with iolence. The same cause is supposed sometimes to produce reat effects in nature, such as splitting rocks, heaving up mounains, and other effects resembling earthquakes. For, suppose hat in the interior of a mountain there were an empty space, ten ards square, and only an inch deep, in which water had lodged o as to fill it entirely; and suppose that a crevice in the earth hould extend from this spot 200 feet above, which should also ecome filled with water by rain or otherwise: the force exerted vould be adequate to shake the mountain, and perhaps rend it sunder.

245. Although the weight of a given quantity of water will ot be altered by varying the shape of the vessel, yet the presure which it exerts on the bottom of the vessel will be greater in roportion as the altitude of the mass is greater, and of course reater in a narrow vessel than in a wide one. If it be asked hy the weight is not increased as the downward pressure is ncreased, the answer is that the pressure in that direction is xactly counterbalanced by an equal pressure in the opposite irection.

Specific Gravity.

246. *The Specific Gravity of a body, is its weight compared ith the weight of another body of the same bulk, taken as a standrd.*

Water is the standard for all solids and liquids, and common ir for the gases. Therefore, the specific gravity of a solid or liquid body is the ratio of its weight to the weight of an equal olume of water; and the specific gravity of an aeriform body, the ratio of its weight to the weight of an equal volume of air ut a ratio is expressed by a vulgar fraction, whose numerator the antecedent and whose denominator is the consequent. If herefore, the weight of a body is made the numerator, and the

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What effect is produced by pouring liquids into casks through long tubes? Vhat effects in nature are supposed to result from the same cause? Can given quantity of water exert a pressure in a vessel greater than its own eight? Define Specific Gravity. What substance is the standard for liuids and solids? What for bodies in the form of air? How is the speci*c gravity of a body expressed by a fraction?*

weight of an equal volume of water the denominator, the value of the fraction, that is, the quotient, will express the specific gravity of the body. Hence, the weight of a body being given, and being made the numerator, every process for finding the specific gravity consists in finding for the denominator the weight of an equal bulk of water or air. The principles upon which the methods of doing this depend, are now to be explained.

247. *A body immersed in a fluid, loses as much weight as is equal to the weight of an equal volume of the fluid.*

Fig. 69.

Let EF (Fig. 69.) be a solid body immersed in a vessel of water or any fluid, and suppose it divided into an indefinite number of perpendicular columns, reaching to the surface of the fluid, as *m o n*. Now the upward pressure at *n* is as its depth, and the downward pressure at *o* as its depth; therefore the upward pressure exceeds the downward, by the weight of a column of water equal to *n o*. The same is true of all the columns, however numerous they may be, that can be drawn parallel to *n o;* but these columns, taken collectively, make up a body of water equal in bulk to the solid. Hence, the solid is pressed upwards, more than downwards, by the weight of a quantity of water of the same magnitude, and consequently loses so much of its weight. Hence, the specific gravity of any solid body that will sink in water, is found by the following

RULE.—*Divide the weight of a body by its loss of weight in water.*

248. When the body whose specific gravity is required is lighter than water, as cork, for example, the object is still to find the weight of an equal bulk of water, since that will constitute the denominator, or divisor, as before. To ascertain this, suspend any heavy body, as a mass of lead or glass, in water and find its weight. Attach to it the lighter body. Now the cork will not only lose all its own weight, but will diminish the weight, of

How much weight does a body lose by being immersed in water? Illustrate by figure 69. Give the rule for finding the specific gravity of a body. How do we proceed when the body is lighter than water?

he heavy body; and the weight of an equal bulk of water will e indicated by the whole of what the cork loses, namely, its wn weight added to the loss occasioned to the other body. Vhence we have the following

RULE.—To find the specific gravity of a body lighter than rater. *Divide its weight by the sum of its weight added to the oss of weight which it occasions in a heavy body previously balanced in water.*

249. A solid which is soluble in water, as a lump of salt, is rotected from solution by smearing it with oil or a thin coat of ees wax; and solids that are very porous and would absorb rater, and thus increase their specific gravities, as certain kinds f wood, are first covered with varnish. The specific gravity f solid substances, which are too minutely divided to be reighed in water separately, as grains of sand or shot, may be ound by weighing them in a small bucket previously balanced n water.

250. The specific gravity of *liquids* may be ascertained by everal different methods.

RULE 1.—*Weigh equal volumes of the liquid and of water nd divide the former result by the latter.*

RULE 2.—*Ascertain the loss of weight of any solid body, first n the liquid and then in water, and divide the former result by the atter.*

Both these rules obviously depend upon the same principles is those explained in Art. 246, the weight of the liquid being mmediately compared with that of an equal bulk of water; but here is another method, founded on the following proposition.

251. *Two columns of fluids of different specific gravities, pressing freely on each other at their bases, balance one another when heir heights are inversely as their specific gravities.*

Let AB (Fig. 70.) be a recurved tube, and let the height of he column of the fluid B be as much greater than that of A, as

Give the rule—How do we proceed when the body would be dissolved n water? Give the rule for finding the specific gravity of liquid. When lo two *fluids of different specific gravities* balance each other in a recurved tube?

Fig. 70.

the fluid B is lighter than the fluid A; the two columns will then be in equilibrio.

If the tube be of uniform bore throughout, then the proposition is manifestly true, because the quantities of matter pressing on each other in opposite directions will be equal, and will have equal momenta; but from the peculiar nature of fluids, (Art. 235.) the opposite pressures will be the same, when the heights of the columns are the same, whatever may be the shape or capacity of the tube. If we introduce mercury into one arm of the tube and water into the other, the graduated scale will indicate that the water stands 13½ times as high as the mercury. Therefore, the specific gravity of mercury is 13½. Proof spirit will stand at .923; sweet oil at .915; and their specific gravities are the same, water being 1.

252. *If a body floats on a fluid, it displaces as much of the fluid as is equal to its own weight.*

If into a vessel full of water a floating body, as a piece of wood, be introduced, the quantity of water displaced will be found to be exactly equal in weight to the body. Or if the vessel full of water be accurately balanced in a scale, and then removed, and the piece of wood introduced, the vessel, on restoring it to the scale, will still remain in equilibrium, the wood exactly compensating for the water it displaced.

253. An accurate knowledge of the specific gravities of bodies, is of great use for many purposes of science and the arts, and they have therefore been determined with the greatest possible precision. The heaviest of all known substances is platina, whose specific gravity, in its state of greatest condensation, is 22, water being 1; and the lightest of all ponderable bodies is hydrogen gas, whose specific gravity is 0.73, common air being 1. By calculation, it will be found that platina is about 247,000 times as heavy as hydrogen, and

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Illustrate by figure 70. When a body floats on a fluid, how much of the fluid does it displace? How is this fact proved by experiment? What is the use of determining the specific gravity of bodies? What is the *heaviest of all* known bodies? What is the lightest? How much heavier is *platina than hydrogen?*

: a wide range is allowed to the various bodies which lie
een these extremes. The metals, as a class, are the hea-
bodies ; next to these come the metallic ores ; then the
ous gems ; and finally, minerals in general, animal, liquid
egetable substances, in order, according to the following

'*s*, (pure,) not including the bases of the alkalies
ınd earths, from - - - - - 5 to 22

ld - - -	19.25	Steel - - -	7.84
icksilver - -	13.58	Iron - - -	7.78
ad - -	11.35	Tin - - -	7.29
ver - -	10.47	Zinc - - -	7.00
pper - -	8.90		

lic Ores, lighter than the pure metals, but usual-
above - - - - - - - - - 4.00
ous Gems, as the ruby, sapphire, and diamond, - 3—4
'als, comprehending most stony bodies, - - 2—3
ds, from ether highly rectified to sulphuric acid
hly concentrated, - - - - - - - ¾—2
in general, heavier than water.
do. lighter ; but the oils of cloves and cin-
non are heavier than water ; the greater part lie be-
een .9 and 1. - - - - - - - .9—1
- - - - - - - - - 1.032
ol (perfectly pure,) - - - - - - .797
, of commerce, - - - - - - - .835
Spirit, - - - - - - - - .923
s ; the specific gravity of the lighter wines, as
ımpagne and Burgundy, is a little less, and of the
vier wines, as Malaga, a little greater, than that
water.
s, cork being the lightest and lignum-vitæ the hea-
st, - - - - - - - - - ¼ to 1¼

. If we balance, in a pair of scales, a tumbler filled
water to a certain mark near the top, and then turn-
t all the water except a small quantity, introduce any
body, (as a tumbler a little less than the first,) so as to
he water on the sides to the same mark as before, the
orium will be restored. Here, the space occupied by the

t is the heaviest class of bodies? What the next? Name other
in order. Give the specific gravities of various classes of bodies,
rals, liquids, &c. Recite the experiment with a tumbler of water
o a certain mark, &c.

solid immersed, is the same with that before occupied by the water. On the same principle, a ship is floated in a dock with a very small quantity of water, and still rides as freely as on the ocean. By the ascent of the water on the sides, the upward pressure on the bottom is increased, on the same principle as in the Hydrostatic Paradox, (Art. 243.) Though, in this case, we cannot say that a quantity of water is *displaced* equal in weight to the solid, (since the whole of the water originally in the vessel may not have been nearly sufficient to fill the space occupied by the ship,) yet the effect is the same, in regard to the pressure on the water below the ship, and of course on the upward pressure, (Art. 229.) as though the space occupied by the ship below the level of the fluid on its sides, were filled with water. On this principle, the weight of a loaded boat in the lock of a canal is easily estimated.

Boats are sometimes made of iron instead of wood, their thickness being so much less, that the entire weight of the boat is not greater than when made of wood.

255. The human body, when the lungs are filled with air, is lighter than water, and but for the difficulty of keeping the lungs constantly inflated, it would naturally float. With a moderate degree of skill, therefore, swimming becomes a very easy process, especially in salt water. When, however, a man plunges, as divers sometimes do, to a great depth, the air in the lungs becomes compressed, and the body does not rise except by muscular effort. The bodies of drowned persons rise and float after a few days, in consequence of the inflation occasioned by putrefaction. Quadrupeds swim much more easily than man, because the motion of the limbs necessary to sustain themselves, nearly coincides with their natural motions in walking, while the body maintains nearly its usual posture.

256. *If a body is held beneath the surface of a fluid, the force with which is will ascend, if it is lighter than the fluid, or with which it will descend, if it is heavier, is equal to the difference between its own weight and the weight of an equal quantity of the fluid.*

On what principle is a ship floated into a dock with a small quantity of water? How is the weight of a loaded boat estimated? What is said of iron boats? How does the weight of the human body compare with that of water? Why do the bodies of drowned persons rise? Why do *quadrupeds swim* more easily than men? With what force will a body held *in the water* endeavor to ascend or descend?

On the foregoing principle is founded the construction of a machine called the Camel, for raising sunken vessels, or for lifting ships over sand banks. Empty hogsheads or boxes sunk by means of weights which are afterwards detached, being fixed to a sunken ship, may give it so much buoyancy as to cause it to float. Suppose, for example, a hundred empty hogsheads were thus attached, what upward force would they exert?

The number of gallons in a hogshead, 63, multiplied by 231, the number of inches in a gallon, gives 14553 inches; which, divided by 1728, gives 8.4 cubic feet in a hogshead. But a cubic foot of water weighs 62½ pounds. Therefore, $62.5 \times 8.4 = 525$ lbs. = weight of a hogshead of water.

Now 100 cubic inches of air weighs 30½ grains; therefore, 100 : 30½ : : 14553 : 4438.66 = grains of air in a hogshead; or (since 437.5 grs. equal an ounce) the number of ounces of air in a hogshead is 10.14. Hence 525 lbs.—10,14 oz. = 534 lbs. 6 oz. nearly, for the upward force of an empty hogshead sunk in water; consequently, the buoyancy of 100 hhds. is 52437.5 pounds or almost 23½ tons.

A similar effect is exhibited in rivers, where the ice is formed upon the stones at their bottom. Ice is specifically lighter than water, and therefore, when it accumulates to a certain degree around the stones, the upward pressure upon the stones exceed their pressure downwards, and they are brought to the surface, having been sometimes torn up with great force. Huge masses of stone appear in many cases to have been floated by the ice adhering to them, and carried to a great distance from the place of their formation.

257. Rocks and stones being only a little more than twice as heavy as water, of course nearly half their weight is sustained while they are immersed in water; and hence the increased weight which is felt when a large stone is lifted from the bed of a river, as soon as it reaches the surface. Large masses of rocks are transported with far greater facility by torrents, on account of their diminished weight. On the same principle, the limbs feel very heavy on leaving a bath. Life boats have a large quantity of cork mixed in their structure; or of air-tight

What is the structure and principle of the Camel? How are sunken ships raised by means of empty hogsheads? What is the amount of buoyancy of 100 hogsheads? State the effect of ice in raising large rocks. Why does a rock feel so much lighter in the water than out of it? State the effect on the *limbs after bathing*. Structure of life boats.

vessels of thin copper or tin plate, so that, even when the boats are filled with water, a considerable part still floats above the surface.

258. The *magnitudes* of bodies may frequently be most conveniently and accurately estimated from the doctrine of specific gravities. Suppose we wish to ascertain the exact number of solid inches contained in a stone of rude and irregular shape, we should find great difficulty in applying to it any linear measurements; but if we ascertain its loss of weight in water, we then have the weight of an equal bulk of water, and since 1000 ounces contain 1728 cubic inches, we may easily find how many cubic inches correspond to the weight of water of equal magnitude with the body in question. For example, when we want to find the number of solid inches in a chain, the irregularity of its shape prevents our applying to it any linear measure; but if we weigh it in water, and subtract this weight from its weight in air, the difference gives us the weight of an equal bulk of water, which we can easily convert into solid inches. Suppose the chain loses 2.34 ounces by being weighed in water, then

$$1000 \text{ oz.} : 1728 \text{ in.} :: 2.34 \text{ oz.} : 4.04 \text{ inches.}$$

That is, the chain contains a little more than four solid inches.

CHAPTER II.

OF LIQUIDS OR NON-ELASTIC FLUIDS IN MOTION.

259. That branch of Natural Philosophy which treats of fluids *in motion*, is usually denominated *Hydraulics*. It embraces the phenomena exhibited by water issuing from orifices in reservoirs—projected obliquely or perpendicularly—flowing in pipes, canals, and rivers—oscillating in waves—or opposing a resistance to the progress of solid bodies.

260. *If a fluid runs through any tube, pipe, or canal, and keeps it constantly full, its velocity, in any part of its course, will be inversely as the area of the section at that part.*

How are the magnitudes of bodies estimated by means of their specific *gravities?* Example in finding the number of cubic inches in a stone of *irregular* shape, also in a chain.

Thus, in a pipe of unequal bore, in different parts, it is obvious that the same quantity of water must, in a given time, flow through the smaller parts of the tube as through the larger: it must therefore flow proportionally faster.

261. This proposition supposes the fluid to move free of all resistance, and hence it can never hold accurately true in practice. In every canal or river, the velocity of the surface is always greater than that of any other part, being less retarded by the friction of the bottom and sides; and in a tube, the particles near the axis always move most rapidly.

It is of consequence to avoid all unnecessary expansions, as well as contractions, in pipes or canals, since there is always a useless expense of force in restoring the velocity which is lost in the wider parts.

262. The phenomena of RIVERS have sometimes been explained on the supposition that rivers are bodies falling freely down inclined planes. But the conclusions deduced from this doctrine, are so at variance with experience, as to be of no value. Were every part of the bed of a river uniform, like a tube, the channel or portion which moves with the greatest velocity, would be in the center of the surface; but inequalities in the sides and bottom usually throw it out of the center, and incline it to one side or the other. The increased velocity of a stream during a freshet, while the stream is confined within its banks, exhibits something of the acceleration which belongs to bodies falling freely down an inclined plane. It presents the case of a river flowing upon the top of another river, and consequently meeting with much less resistance than when it runs upon the rough uneven surface of the earth itself. The augmented force of a stream in a freshet, arises from the simultaneous increase of the quantity of water and the velocity. In consequence of the friction of the banks and beds of rivers, and the numerous obstacles they meet with in their winding course, their progress is very slow; whereas, were it not for these impediments, it would become immensely great, and its effects would be exceedingly disastrous. A very slight declivity is sufficient for giving the running motion to water. Three

Does the foregoing proposition hold good in practice? What portion of a stream moves with the greatest velocity? How is it in a tube? What is said of all unnecessary expansions and contractions in tubes or canals? On what principles have the phenomena of Rivers been explained? Do the conclusions of the theory agree with experience? What is the *cause of the increased* velocity of a river during a freshet? How *great a declivity is necessary* in order just to give motion to water?

inches per mile, in a smooth, straight channel, gives a velocity of about three miles per hour. The Ganges, which gathers the waters of the Himalaya Mountains, the loftiest in the world, at the distance of eighteen hundred miles from its mouth, is only eight hundred feet above the level of the sea,—that is, about twice the height of St. Paul's church in London; and to fall these eight hundred feet, in its long course, the water requires more than a month. The great river Magdalena, in South America, running for a thousand miles between two ridges of the Andes, falls only five hundred feet in all that distance.

263. *The velocity with which a fluid issues from a small orifice in the bottom or side of a vessel, kept constantly full, is equal to that which a heavy body would acquire, by falling from the level of the surface to the level of the orifice.*

In the construction of water works, it is customary to conduct the stream, or such a part of it as is required, into a cubical cistern, and to let it issue from the side of this, near to the bottom, and thus fall upon the main wheel. Instead of admitting the water to the wheel in this manner, it has sometimes been supposed that an advantage might be gained by letting the water fall down a height equal to that of the top of the cistern, perpendicularly upon the wheel, on the supposition that we might thus avail ourselves of the force acquired by the water in falling. But according to the preceding proposition, the force would be the same whether the water issued from the cistern and thus applied itself to the wheel, or whether it fell upon the wheel from a height equal to that of the surface of the water in the reservoir above the orifice. This is true in *theory;* but in *practice* it would be found more advantageous to take the water out of the cistern, since the force of water falling through the air is considerably diminished by the resistance of the air.

264. *The quantities of water which issue from orifices of the same dimensions, in the side of a cistern or column, are proportional to the square roots of their depths below the surface of the fluid.*

What is the velocity due to a descent of three inches per mile? How high is the source of the Ganges above the sea—the great river Magdalena? With what velocity does a fluid issue from the bottom or side of a vessel kept constantly full? Is it better to let water *fall* on a wheel or issue from a cistern at the same depth?

According to the last proposition, the velocities are equal to those acquired by bodies falling freely through the depths of the orifices ; but the velocities acquired by falling bodies are as the square roots of the spaces ; that is, the *velocities* are proportional to the square roots of the depths ; and since the quantities must evidently vary as the velocities, therefore, the quantities discharged by orifices of the same size at different depths are as the square roots of their depths.

Accordingly, an orifice sixteen inches from the surface, will discharge twice as much in a given time as one four inches deep : and in order to draw off from a given cistern four times as much as before, we must place the orifice or gate sixteen times as deep. A gate opened in a reservoir at the depth of 64 inches, will discharge only four times as much as it would at the depth of 4 inches.

265. *If a cylindrical or prismatic vessel, of which the horizontal section is every where the same, is filled with fluid, and empties itself by an orifice, the velocity with which the surface descends, and also the velocity with which the water issues, is uniformly retarded.*

The velocity with which the surface descends is proportional to that with which the fluid issues from the orifice, and therefore is as the square root of the depth. But the velocities of bodies projected perpendicularly upwards are in the same ratio to their spaces, and therefore a body projected perpendicularly upwards, is in the same relative circumstances as the descending surface of the fluid ; and as the projected body is uniformly retarded, the same is true of the descending surface.

On this principle is constructed the *Clepsydra*, or water-clock. Since the descent of the surface is uniformly retarded, the spaces which it describes in equal times, reckoning from the bottom, are as the odd numbers 1, 3, 5, 7, &c. ; and if a cylindrical vessel of water be furnished with an orifice at the bottom which will exactly discharge the whole column in twelve hours, and the sides of the vessel be divided into spaces corresponding to the foregoing numbers, the successive heights of the column become measures of time.

State the proportion between the respective quantities of water that issue from orifices at different depths? How much more water will an orifice 16 inches below the surface discharge than one only 4 inches? How much more will a gate opened in a reservoir discharge at the depth of 64 inches than at the depth of 4 inches? At what rate is the velocity of the surface of a fluid issuing from an opening in a vessel retarded? Explain the structure of the water-clock, or Clepsydra.

266. *If we accurately mark the time in which a cylindrical or prismatic vessel, whose horizontal section is every where the same, discharges itself to the level of a given orifice, and then draw off for the same time, keeping the vessel constantly full, we shall obtain double the quantity of fluid in the latter case as in the former.*

When the vessel is kept constantly full, the velocity at the orifice (and of course the quantity discharged) continues uniformly the same as at first; and since the circumstances of this case are exactly analogous to those of a body projected perpendicularly upwards; and since, if a body thus projected were to continue to ascend with the first velocity, it would pass over a space twice as great in the same time as when uniformly retarded; therefore, the truth of the proposition is manifest.

267. *A fluid spouting from the side of a vessel, describes the curve of a parabola.*

The fluid is precisely in the same circumstances as a projectile acted on by the force of projection, (viz. the pressure of the incumbent fluid,) and by the force of gravity. Therefore, according to Art. 83, it describes the curve of a parabola. As in the case of other projectiles, the proposition holds good, whatever may be the angle of elevation of the jet.

268. *When a fluid spouts from the side of a perpendicular column, its random or horizontal distance will be the greatest when it spouts from the center, and it will be equal at equal distances from the center above and below.*

The lower parts of the column being subjected to the strongest pressure, namely, that of the incumbent column, we might suppose that the lower the orifice, the greater would be the random; but we must recollect, that such a spout would reach the plane sooner than those at a higher elevation.

269. The term FRICTION is applied to the obstruction occasioned to the passage of fluids in the same manner as it is to

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State the case of a fluid discharging itself from a given orifice when the vessel is kept full. What curve does a spouting fluid describe? From what part of the column must a fluid spout to strike at the greatest horizontal distance? At what two points will the distances be equal? How is the term Friction used in hydraulics?

solids; and it exists to such an extent as to become an object of considerable inconvenience in practice. It can be obviated only by making the conveying pipe of much larger dimensions than would otherwise be necessary, so as to allow the free passage of a sufficient quantity of fluid through the center of the pipe, while a ring or hollow cylinder of water is to be considered to be at rest all around it. Other circumstances beside friction likewise tend to diminish the quantity of fluid which would otherwise pass through pipes,—such as the existence of sharp or right angled turns in them, permitting eddies or currents to be formed, or not providing for the eddies or currents that form naturally, by suiting the shape of the pipe to them. It follows, therefore, that whenever a bend or turn is necessary in a water pipe, it should be made in as gradual a curve or sweep as possible; that the pipe should not only be sufficiently capacious to afford the necessary supply, but should be of a uniform bore throughout, and free from all projections or irregularities against which water can strike, and form eddies or reverberations, since these will impede the progress of the fluid as effectually as the most solid obstacles.

270. An unexpected facility is gained in the discharge of a fluid from the bottom or side of a vessel, by applying a *pipe to the orifice*. On account of the friction known to occur in the passage of a fluid through a tube, it might be supposed that a simple orifice made in the vessel might be more favorable to the discharge of the fluid than an opening prolonged by a tube; but it has been found by experiment, that a vessel of tin, with a smooth hole formed in its bottom, did not discharge water as rapidly as another containing the same weight of water, and an orifice of the same dimensions, to which a short pipe was applied. By varying the length of the pipe, it is found that when its length is twice its diameter, it produces the most rapid discharge, delivering, in this case, 82 quarts of water in 100 seconds, while the simple hole delivered but 62 quarts in the same time. If, however, the pipe projects into the vessel, the quantity discharged is diminished instead of being increased by the pipe.

How is it obviated? What other circumstances diminish the quantity of fluid which would otherwise be discharged by a pipe? How should these impediments be guarded against? What facility is gained in the discharge of a fluid by applying a pipe to the orifice? What should be the length of the pipe compared with its diameter? Effect when the pipe projects into the vessel?

When a fluid is contained in any vessel, it presses equally on opposite points of the vessel, and is thus maintained at rest. Now, if we remove the pressure from one of the opposite points, while it remains on the other, the force exerted on the latter will tend to move the vessel in that direction. Thus, if we suspend a bottle of water, like a pendulum, and open a small plug on one side, the pressure on this side being taken off, but still remaining on the other, the bottle will swing towards the side opposite the orifice, and remain suspended at a certain height above its former position.

Barker's Mill acts on the foregoing principle. Its construction is as follows. AB (Fig. 71,) is a hollow cylinder movable about a vertical axis MN. PP′ is another cylinder, placed at right angles to the former, and communicates internally with it. Near its extremities, which are closed, two apertures are made in the sides of this horizontal cylinder, opening in opposite directions. That at P is supposed to front the reader; that at P′ is supposed to lie on the opposite side of the tube from that on which he looks. Water is supplied by the spout O, keeping the perpendicular cylinder constantly nearly full. As the water flows out at P and P′, the unbalanced pressure on the sides of the cylinder, opposite to those openings, acts on the respective arms PB and P′B, and sets the horizontal cylinder revolving, carrying along with it the perpendicular shaft MN, and any machinery connected with it.

Fig. 71.

The power resulting from the pressure of a column of water is here applied to a very great advantage; for, since the arms of the horizontal shaft BP and BP′ may be lengthened at

Effect on opening a plug in a suspended body of fluid? Why does the bottle swing the opposite way? Describe the construction of Barker's Mill. What mechanical advantages attend this mode of applying the pressure of water?

pleasure, while the power is still applied at its extremity, the circumstances are the same as when a power is applied to the end of a lever, or the circumference of a wheel; it therefore gains a similar mechanical advantage. Moreover, the *centrifugal* force acquired by the revolving fluids, being greatest at the extremities of the shaft, acts under the same advantage, and conspires with the simple pressure.

This machine is said by writers on mechanics, to be the most effective known for applying the power of a given quantity, and a given fall of water, to the working of machinery.*

CHAPTER III.

OF CAPILLARY ATTRACTION, OF THE RESISTANCE OF FLUIDS, AND OF WAVES.

Capillary Attraction.

271. The definition of a fluid, proceeds on the supposition that fluids are destitute of cohesion, and that their particles move among themselves without the slightest impediment. All *liquids*, however, have in fact more or less cohesion or mutual attraction among their particles. This is apparent in their forming drops, and in the viscidity of certain liquids, as oil and tar, which on account of this property are sometimes denominated *semi-fluids*. It is owing to this property that water so readily forms itself into drops, and that its surface, when viewed in a small cup or wine glass, appears convex. Both of these properties are still more observable in quicksilver, which, when poured on a table, forms numerous globules of a perfectly spherical figure; and the convex figure of the surface, as seen in a wine glass, is very striking. When we dip a glass tube into water, it comes out covered with drops of the fluid, which are held by the attraction of the glass for water; but the tube when dipped into quicksilver comes out dry, because the cohesion between the particles of quicksilver for one another is greater than the mutual attraction that exists between the metal and the glass. Hence, a solid body when immersed in a fluid, is sometimes wet by it and sometimes not, according as the at-

Why do drops of water adhere to glass, while quicksilver does not?

* *See Mosely's Mechanics applied to the Arts*, p. 231.

traction between the solid and the fluid is greater or less, than that which exists between the particles of the fluid for one another.

272. Capillary Attraction *is the attraction which causes the ascent of fluids in small tubes.*

The tubes must be less than one tenth of an inch in diameter, and tubes whose bore must be no larger than a hair, (*capillus*,) present the phenomenon the more strikingly. But though the rise of water above its natural level is most manifest in small tubes, it appears, in a degree, in all vessels whatsoever, by a ring of water formed around the sides, with a concavity upwards.

273. When small tubes, open at both ends, are immersed perpendicularly in any liquid, the liquid rises in them to a height which is inversely as the diameter of the bore. Though tubes of glass are usually employed in experiments on this subject, yet the tubes made of any other material, exhibit the same property. Nor does the thickness of the solid part of the tube, or its quantity of matter, make the least difference, the effect depending solely on the attraction of the surface, and consequently extending only to a very small distance.

Fluids rise in a similar manner between the plates of glass, metal, &c. placed perpendicularly in the fluids, and near to one another. If the plates are parallel, the height to which a fluid will rise is *inversely as the distance between the plates;* and the whole ascent is just *half that which takes place in a tube* of the same diameter. If the plates be placed edge to edge, so as to form an angle, and they be immersed in water, with the line of their intersection vertical, the water will ascend between them in a *curve*, having its vertex at the angle of intersection.

274. Various *Phenomena* in nature and art are explained upon the principles of capillary attraction. Capillary action is not confined to tubes, but is exerted among all substances which are perforated by pores, or subdivided by fissures or

Define *Capillary Attraction.* How small must the tubes be? How does capillary attraction exhibit itself in larger vessels? Is it essential that capillary tubes should be of glass? How do fluids rise between glass plates? Does the thickness of the tube make any difference? Explain certain natural phenomena that depend on capillary attraction in the vegetable and animal kingdoms.

interstices. On this power depend chiefly the functions of the excretory vascular system in plants and animals, and hence also the ascents of humidity through the shivered fragments of rocks, unglazed pottery, gravel, earth, and sand. Thus, if the pores of the human skin (which are known to be exceedingly small) are estimated at the $\frac{3}{1000}$ part of an inch in diameter, they will support the fluids that circulate through them to the height of 120 inches, or ten feet, or higher than is required for the animal system. The ascent of the sap in trees has usually been ascribed to capillary attraction, their circulating vessels being a congeries of small tubes; but physiologists now maintain that this action is dependent, not on the mechanical structure, but upon something which they denominate the *living principle* of vegetables.

275. According to Professor Leslie, if a soil of gravel contains pores the 100th part of an inch in diameter, water will ascend in it by capillary action more than four inches; and supposing the particles of coarse sand to have interstices of the 500th part of an inch, the water would rise through a bed of sixteen inches; and if the pores were diminished to the 10,000th part of an inch, water would rise twenty-five and a half feet. Hence, in agriculture, are derived the advantages of deep and perfect tillage; since the more effectually a soil is pulverized, the better fitted it is to raise and retain water near the surface.

Several familiar examples of capillary attraction may be added. A piece of sponge, or a lump of sugar, touching water by its lowest corner, soon becomes moistened throughout. The wick of a lamp lifts the oil to supply the flame, to the height of several inches. A capillary glass tube, bent in the form of a syphon, and having its shorter end inserted into a vessel of water, will fill itself and deliver over the water in drops. A lock of thread or of candle wick, inserted in a vessel of water in a similar manner, with one end hanging over the vessel, will exhibit the same result. An immense weight or mass may be raised through a small space, first by stretching a dry rope between it and a support and then wetting the rope.

Is the ascent of sap in trees owing to this cause? How high will water ascend in gravel containing pores 100th of an inch in diameter? How high through pores of the 500th, and 10,000th of an inch? Use of deep tillage. How is capillary attraction exhibited in a sponge, wick of candle, &c. Force created by a wetted rope.

Resistance of Fluids.

276. *The risistance which a plane surface meets with while it moves in a fluid, in a direction perpendicular to its plane, is proportioned to the square of its velocity.*

Hence, a boat in the water encounters but little resistance when moving slowly, but the resistance increases rapidly as the speed is augmented. Doubling the velocity increases the resistance fourfold; tripling the velocity renders the resistance nine times what it was before. This proposition is found to hold good in practice, where the velocity is very small, as in the motions of boats or vessels in water; but when the velocity becomes very great, as that of a cannon ball, the resistance increases in a much higher ratio than as the square of the velocity. Since action and reaction are equal, it makes no difference, in the foregoing proposition, whether we consider the plane in motion and the fluid at rest, or the fluid in motion and striking against the plane at rest.

On account of the rapidity with which the resistance increases as the velocity is augmented, when a vessel or a steamboat is moving in water, it is only a comparatively moderate velocity that can possibly be given to it. A vessel driven by a wind which moves 60 miles an hour, is not carried forward faster than at the rate of 12 or 14 miles per hour. Steamboats are sometimes urged forward at the rate of 16 miles an hour; but to gain the additional speed over and above 12 miles, requires a great expenditure of force. If a steam engine of 20 horse power give a motion of 4 miles an hour, it would require one of 180 horse power to increase the speed to 12 miles an hour. But, it must be observed that the resistance decreases as fast when the velocity is diminished, as it increases when the velocity is augmented; and consequently, that canals may have the advantage over railways, when heavy articles are to be transported by very slow motions, although railways, encountering only the resistance of the air instead of water, have greatly the advantage when the motion is swift.

It follows from the foregoing doctrine that a body descending freely through the air by gravity for a great distance, does not

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Resistance of fluids. How is the resistance proportioned to the velocity of the moving body? Exemplified in a boat moving slowly and rapidly. Why can only a moderate velocity be given to a vessel or steam-boat? What advantage in point of resistance, have railways over canals? What advantages have canals over railways? Do falling bodies continue to be uniformly accelerated till they reach the ground?

continue to be accelerated throughout the whole distance, but is finally brought, by the resistance of the air, to a uniform motion.

277. The motion of fluids in pipes and otherwise, is modified so much by the impediments arising from friction against the sides of the pipe or channel, from resistance of the air, and from more or less cohesion in the fluid itself, that the foregoing principles, deduced from theory, require great allowances to be made when applied to practice. The nature of these impediments, however, is so well understood, that the theoretical principles of hydraulics may be reduced to practice without an error exceeding one fifth or even one tenth of the whole.

278. *Undulation of Fluids and the formation of Waves.*

When the surface of water is pressed upon equally, in parts contiguous to one another, the columns most pressed are shortened, and sink beneath the natural level of the surface, while those that are least pressed are lengthened, and rise above that level. As soon as the former columns have sunk to a certain depth, and the latter have risen to a certain height, their motions are reversed, and continue so, until the columns that were at first most depressed have become most elevated, and those that were most elevated have become most depressed. *The alternate elevations and depressions of the surface of a body of water, produced by a force acting unequally on the surface, are called waves.* The water in the formation of waves has a vibratory or reciprocating motion, both in a horizontal and in a vertical direction, by which it passes from the columns that are shortened to those that are lengthened, and returns again in the opposite direction. *Progressive* motion is not necessary to undulation.

279. Sir Isaac Newton first observed the analogy between the motions of waves and the vibrations of a column of water in a recurved tube, and upon this analogy he founded his theory of waves. Let AFGB (Fig. 72.) be a bent tube, of equal bore throughout,

How are the foregoing principles to be modified when applied to the motion of fluids in pipes? What amount of error is involved in the application of the theoretical principles of hydraulics? Define waves. Describe the kinds of motion that constitute waves. Is progressive motion essential to undulation? Show the analogy between the motions of of waves and the vibrations of a column of water in a recurved tube.

having its sides parallel to each other and perpendicular to the horizon. Suppose it to be filled with water or any fluid to the height MM′. By any pressure applied at M′, let the column be depressed to N′ and raised to E in the opposite arm. The pressure being removed, the longer column EF will preponderate, and seek to regain its original level, but the ascending column will not stop at M′, but on account of it inertia will ascend to E′, that is, to the same height as that from which it descended on the other side. It will now descend again, and these reciprocal motions will continue until destroyed by the natural impediments to motion. On account of these, each successive vibration is shorter than the preceding, but all of them, like those of a pendulum, are performed in equal times; for the moving force is obviously proportioned to the column EM, that is, to the space through which the whole column vibrates; and when the forces are as the spaces, the times are equal.

Fig. 72.

280. Now when the surface of water is smooth and at rest, if any force (as the action of the wind or the fall of a stone) depress that surface in any particular place, the contiguous water will necessarily rise all around that place. The water which has thus been elevated, descends soon after in consequence of its gravity; and by the time it has reached the original level, it will have acquired velocity sufficient to carry it lower than that level; therefore, it now acts as another original moving force, in consequence of which, the water will be raised on both sides of it. And for the same reason, the descent of those elevated parts will produce other elevations contiguous to them, and so on. Thus the alternate rising and falling of the water in ridges, will expand all around the original place of motion; but as they recede from that place, so the ridges as well as the adjoining hollows, grow smaller and smaller until they vanish. This diminution of size is produced by three causes, namely, by the want of perfect freedom of motion amongst the particles of water, by the resistance of the air, and by the remoter ridges being larger in diameter than those which are nearer.

Explain why when a stone is thrown into water, circles are formed all *round* the place where it falls.

281. From a variety of experiments and observations, it appears that the utmost force of the wind cannot penetrate a great way into the water; and that even in violent storms the water of the sea is slightly agitated at the depth of twenty feet below the usual level, and probably not moved at all at the depth of thirty feet. Therefore, the actual displacing of the water by the wind cannot be supposed to reach nearly so low; and hence it would seem that the greatest waves could not be so very high as they are often represented by navigators. But it must be observed, that in storms waves increase to an enormous size from the *accumulation of waves upon waves*; for, as the wind is continually blowing, its action will raise a wave upon another wave, and a third wave upon a second, in the same manner as it raises a wave upon the flat surface of the water. In fact, at sea, a variety of waves of different sizes are frequently seen one upon the other, especially while the wind is actually blowing. When it blows fresh, the tops of the waves, being lighter and thinner than the other parts, are impelled forward, broken, and turned into a white foam, particles of which, called *spray*, are carried to a great distance. Whilst the depth of the water is sufficient to allow the oscillation to proceed undisturbed, the waves have no progressive motion, and are kept, each in its place, by the action of the waves that surround it. But if by a rock rising near to the surface, or by the shelving of the shore, the oscillation is prevented or much retarded, the waves in the deep water are not balanced by those in the shallower, and therefore acquire a progressive motion in this last direction, and form *breakers*. Hence it is that waves always break against the shore, whatever be the direction of the wind.

282. *Questions in Hydrostatics.*

1. In a Hydrostatic Press, (Fig. 64.) the height of the small column AB, on which the power acts, is 2 feet above the bottom of the larger piston CD; the diameter of the cylinder AB is one inch, and of the cylinder CD 1 foot. By means of a screw turned by a lever, a man can exert a force on A equal to 500 lbs. What amount of pressure can he apply with the aid of this press, combining his own strength with the pressure of the column of water AB?

Ans. 72098.17 lbs.

Does the wind penetrate far into water? To what depth is the sea agitated in storms? Explain the formation of *spray*. Also *breakers*. Why do waves *break against* the shore?

2. A Junk Bottle, whose lateral surface containe inches, was let down into the sea 500 fathoms (: What pressure would the sides of the bottle sustain ance being made for the increased specific gravity of

Ans. 65104.

3. A Greenland Whale sometimes has a surfa square feet: What pressure would he bear at the d fathom?

Ans. 1080,000,000 lbs. *or more than* 4821

4. A mineral weighs 960 grains in air, and 73 water: What is its specific gravity? Ar

5. What are the respective weights of two eq masses of gold and cork, each measuring 2 feet on its l

Ans. *The gold weighs* 9625 lbs.$=$4.278 *tons; the* 125 lbs. (See Art. 253.)

6. On one of the peaks of the Alps, is a single mas rock of nearly a globular shape, which is estimated to contain 5049 cubic feet. The whole mass is balanced on its center of gravity, that a single man m rocking motion. By trial made upon a small fragm cific gravity was found to be 2.6: What is its weigl

Ans. 366.2

7. Wishing to ascertain the exact number of cubi a very irregular fragment of stone, I ascertained weight in water to be 5.346 ounces: Required its d

Ans. 9.238 *cub*

PART III.—PNEUMATICS.

CHAPTER I.

OF THE MECHANICAL PROPERTIES OF AIR.

283. PNEUMATICS *is that branch of Mechanics which treats of the equilibrium and motion of elastic fluids.*

Those laws of equilibrium which are founded on the peculiar nature of fluids, arising from the mobility of their particles, are equally applicable to Hydrostatics and Pneumatics. But certain additional properties result from the *elasticity* of vapors and gases, which may be conveniently considered under the latter head.

284. *Vapors* are elastic fluids which are produced from liquid or solid bodies, by the agency of heat, and which readily become liquid or solid again on the application of cold. Thus steam is raised from boiling water, and is again easily condensed by cold into the liquid state. *Gases* are permanently elastic fluids. They are never met with in nature, either in the liquid or solid state, and it is only by means of extraordinary degrees of cold or pressure, that they can be made to give up their elasticity and become liquids. Atmospheric air is a body of this class; and since air and steam are, with slight exceptions, the only elastic fluids employed as mechanical agents, it is to these, chiefly, that our attention will be devoted.

285. The properties of air may be exhibited under the form of a few simple propositions.

(1.) *Air is material.*

The two essential properties of matter are extension and impenetrability. That air has extension, needs no proof. That it is impenetrable, or has the property of excluding all other matter from the space which it occupies, is proved by experi-

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Pneumatics.—Define Pneumatics. What laws are equally applicable to Hydrostatics and Pneumatics? Upon what property do the peculiar principles of pneumatics depend? Distinguish between vapors and gases. Which of the different aeriform bodies are chiefly considered in mechanical philosophy? Is air material? How is it proved to have the two essential properties of matter?

ment. Thus, if we depress in water a tall jar, or a tumbler, we shall find that the water rises only through a certain *part* of the vessel, to whatever depth we immerse it; and if, to a hollow cylinder, made smooth and closed at the bottom, we fit closely a stopper or solid cylinder, called a piston, moving freely in it, on applying the piston, no force will enable us to bring it into contact with the bottom of the cylinder, unless we permit the air within it to escape. Two other properties exhibited by air, likewise indicate that it is material: these are *inertia* and *weight*. The inertia of air is manifested by the resistance it opposes to bodies moving in it; as, for example, an open umbrella moved through the air, in a direction parallel with the staff; and the weight of the air is shown by the fact that a vessel, as a bottle, from which the air has been withdrawn, (by methods to be described hereafter,) weighs less than before. A vessel of the capacity of a wine quart, weighs about eighteen grains less after the air is exhausted, than before. One hundred cubic inches of air weigh thirty grains and a half.

(2.) *Air is a fluid.*

This property is manifested not only by the great mobility of its parts, but also by the distinguishing property of fluids, viz. that any portion of air at rest, presses and is pressed equally in all directions; and that a pressure or blow applied to any part, is propagated through the whole mass, and affects every part alike.

(3.) *Air is an* ELASTIC *fluid.*

Thus, when an inflated bladder is compressed, it immediately restores itself to its former situation. Indeed, since air, when compressed, restores itself, or tends to restore itself, with the same force as that with which it is compressed, it is a *perfectly elastic* body.

286. Before we proceed further, it is necessary for the learner to be made acquainted with the apparatus, by which the mechanical properties of air are illustrated.

The Air Pump.

The Air Pump, (Fig. 73.) is an instrument used for the purpose of exhausting the air from any given space. Though

What other two properties of matter are exhibited by air? What is the weight of one hundred cubic inches of air? How is it proved that *air is a fluid?* How proved that air is an elastic fluid? Describe the *air pump.*

Fig. 73.

of several different forms, yet the most common construction is that represented in Fig. 73. The chief parts are the *plate* A, the *barrels* EE, and the *pipe* or *canal* C, leading from the plate to the barrels.—The glass vsssels which are set upon the plate, are called in general *receivers*. A *guage* is sometimes employed (as represented by D in the figure) to indicate the degree of exhaustion; but the nature of this appendage will be better understood hereafter. Such is the construction of the air pump in general; but the importance of this apparatus entitles it to a more minute description. In order, then, fully to understand the principle of the air pump, and other kinds of apparatus designed for producing a vacuum, we must understand the construction of *valves*, and of the *cylinder*, and *piston*.

287. *A* VALVE *is a contrivance which permits a fluid to pass in one direction, but prevents its passing in the opposite direction.* The clapper seen on the under side of a pair of bellows, is a familiar example of a valve. The valve employed in the air pump, usually consists merely of a strip of oiled silk, tied over a small orifice. The air by pressing *outwards* from the orifice, raises the silk, opens the valve, and makes its escape; while by pressing *inwards* upon the orifice, it keeps the strip of silk close to the orifice, and is therefore prevented from passing in that direction. The piston and cylinder are exemplified in a common syringe. It consists of a hollow cylinder, or barrel, to which is fitted a short solid cylinder called the piston, which is moved up and down the barrel by means of a projecting handle called the piston-rod, and is fitted so closely to the barrel

Point out the plate, the barrels, the conducting pipe, the receivers, the guage. Define a valve—exemplified in a bellows. How are the valves *of the air pump constructed?* How does the valve operate?

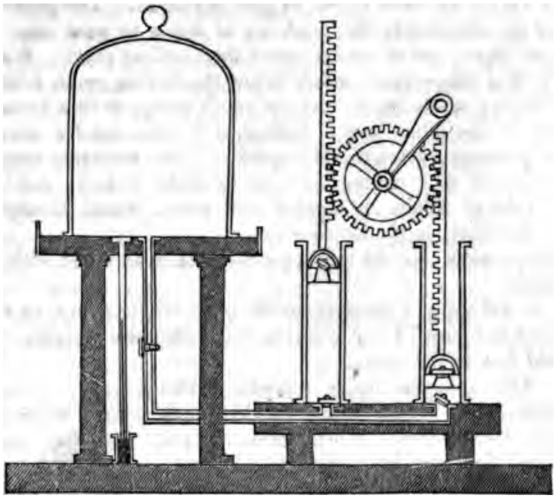
as to be air tight. Suppose now that the cylinder is in a perpendicular position, closed below, but open above, and that the piston rests on the bottom. On drawing up the piston, the air above it is lifted out, and the space below it is a vacuum. If a small orifice be made in the bottom of the barrel, then, as the piston is drawn upwards, the air will flow in and no vacuum will be formed; and as the piston is depressed again, the air is forced back. But by attaching a valve to the orifice, we may admit or exclude the external air at pleasure. If the strip of silk be tied on the *outside*, then, on drawing up the piston, the air will not follow, but the piston will go up heavily, since it lifts up the entire weight of the column of air that rests upon it, (there being nothing below it to act as a counterpoise,) and if the hand be withdrawn from the piston rod, the piston will descend spontaneously. Again, if the valve be placed on the *inside*, then the external air will follow the piston as it rises, and no vacuum will be formed. If now the piston be depressed, the air cannot be expelled, (since the valve closes on the orifice in that direction,) and the piston cannot be forced down to the bottom of the barrel, unless a valve is placed in the piston itself, opening outwards; in this case, the air of the barrel may be expelled by depressing the piston.

288. We have been thus minute in the description of the construction of valves, and of the cylinder and piston, because when these things are clearly understood, the learner will easily comprehend the principle of the air pump, of the common house pump, of the steam engine, and of every other species of pneumatic apparatus. Let us now return to the *air pump*.

In the barrels, two pistons play up and down, each of which is furnished with a valve opening upwards into the open space, through which the piston rods move. Another valve is placed at the bottom of each barrel, opening into the barrel. The piston rods are indented bars, to which a toothed wheel (concealed in Fig. 73, but seen in Fig. 74,) is adapted, which, being turned backwards and forwards by means of the winch G, (Fig. 73.) alternately raises and depresses the two pistons, as is represented in Fig. 74. Suppose now the receiver to be placed on the plate of the pump, one of the pistons being at the top, and the other at the bottom of the barrel. We turn the winch, the piston rises, and the air of the receiver opens the valve at the bottom of the barrel, and diffuses itself equally

Describe a piston and cylinder as exemplified in a common syringe. How is a valve applied to it?

Fig. 74.



through the barrel and the receiver. We turn the winch in the opposite direction, the piston descends, compresses the air in the barrel before it, which, as it cannot go back into the receiver, opens the valve in the piston itself, and escapes into the vacant space in which the arm of the piston moves. This process is repeated every time the piston rises and falls; and it is the same in both barrels, two being employed to accelerate the process of exhaustion. The pressure on the descending also helps to raise the ascending piston.

289. By means of this instrument, we may obtain very striking illustrations of the mechanical properties of air.

(1.) The *pressure* of the air acts with great force on all bodies at the surface of the earth, amounting, as we shall show hereafter, to nearly 15 pounds upon every square inch, or more than 2000 pounds upon a square foot. Upon so large a surface, therefore, as that of the human body, the pressure amounts to no less than 13 or 14 tons; but being so uniformly distributed within and without, and on all sides, it is, when the air is at rest, scarcely perceptible. In consequence of this pressure,

Describe the interior structure of the air pump from figure 74. Show how the exhaustion is effected. What is the amount of the pressure of the atmosphere on every square inch of surface—also on every square foot? *What is the whole* amount on the human body?

the air insinuates itself into all fluids, and fills the pores of all solids except the most dense, as gold or platina. The pressure of the air diminishes the tendency of fluids to pass into the state of vapor, and of course raises their boiling point. Warm water, at a temperature much below the boiling point, will be set a boiling under the receiver of an air pump, or in a vacuum formed in any other way. Indeed, if it were not for atmospheric pressure, water would require only the moderate heat of 72 instead of 212 degrees of heat to make it boil; and the more volatile fluids, as alcohol and ether, would hardly be found in nature, in the liquid state.

Experiments like the following may easily be made with the air pump.

1. If we apply a receiver to the plate of the pump, as represented in figure 74, on working the pump the receiver will be held fast to the plate.

2. The annexed figure represents two hemispheres of brass, closely fitted to each other at their edges. When these are put together, they can be pulled asunder with very little force, so long as the pressure of the air acts on the inside as well as on the outside. But now, join the parts together, and screw the ball to the plate of the pump. After exhaustion, on removing it, and attaching the handle, represented at the bottom of the figure, the hemispheres will be found to be pressed so closely together as to require great force to separate them.

Fig. 75.

This piece of apparatus is called the *Madgeburg Hemispheres*, having been first exhibited at Madgeburg by Otto Guericke, the inventor of the air-pump. Guericke had a pair of hemispheres constructed so large, that sixteen horses, eight on each side, drawing against each other, were unable to pull them asunder.

3. If a *square** bottle, mounted with a screw, (as in the preceding figure,) be attached to the plate, on exhausting the air, the sides of the botttle will be crushed inwards, with a loud explosion, and the glass be found broken into minute fragments.

Does air penetrate fluid and solid bodies? How does the pressure of the atmosphere affect the boiling point of fluids? If it were not for this, at what temperature would water boil? Describe the Madgeburg hemispheres, and the experiment with them. Also with a square bottle.

**This experiment* shows how much less adapted to sustain pressure a flat surface is than a round, since a globular vessel of equal thickness would not be broken.

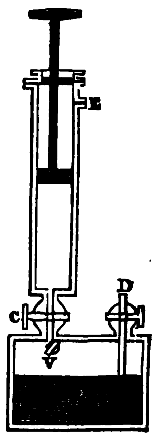
n this experiment, a blanket or towel should be spread over he bottle to prevent injury to the eyes.

(2.) The *elasticity* of the air is such, that the smallest porion of it may be expanded beyond any known limits, by reoving the external pressure. By this means, a bubble may e made to fill a very large space. On the other hand, air as been condensed by pressure, until its density has been reater than that of water, siill retaining the elastic invisible tate. In consequence of its elasticity, air is set in motion by e least disturbance of its equilibrium, whether by condensaon or rarefaction, thus giving rise to the phenomena of winds.

(3.) Air is essential to the support of *combustion*, and to the *espiration* of animals; and finally, it is the principal medium f sound. It may be farther shown, that the weight of bodies s diminished by the buoyancy of air, (acting on the same priniple as water,) and that light bodies are sustained in it, in conequence of its greater specific gravity, while, in a vacuum, odies of various density, as a guinea and a feather, fall towards the earth with equal velocities.

The Condenser.

Fig. 76.



290. The condensation of air is usually ffected by means of the *Condensing Syrnge*. This instrument is a cylinder and iston, the cylinder having a valve opening utwards, while the piston is without a valve. The principle of its operation will be readily nderstood from the figure. Near the top of he cylinder is a small hole in the side, which s immediately below the piston, when this is rawn up to the top of the cylinder. On orcing down the piston, the air is driven beore it, and expelled through the valve at the ottom. By connecting a bottle or other lose vessel with the bottom, the air expelled nay be driven into that, its return being preented by the same valve. The piston beng drawn up again above the opening in the ylinder, another similar portion of air may e forced into the condensing bottle; and hus the process may be continued indefinitely.

To what extent may air be dilated and compressed? How is air set n motion? What relations has air to combustion, respiration, and ound? *How is the weight of bodies affected by the buoyancy of the ir? Describe the Condensing* Syringe from figure 76.

291. The *Condensing Fountain* is a bottle, usually of copper, partly filled with water, upon the surface of which the air is condensed by means of the condensing syringe. The fluid being thus brought under a strong pressure, it tends to issue with great force whenever a pipe, that is inserted in the bottle, and extends below the surface of the water, is opened. The celebrated spouting springs of Iceland, called the *Geysers*, in which water accompanied by large masses of rock, is thrown to the height of 200 feet, arise from pneumatic pressure acting upon the surface of water in the interior of the earth, the aeriform substance, whatever it may be, being produced by means of volcanic action.

292. The *Air-Gun* is an instrument in which condensed air is substituted as the moving force instead of gun-powder. By means of a condensing syringe, air is strongly condensed in a metallic ball, furnished with a valve at the mouth, where it is screwed on the gun below the lock. As the lock is sprung, it falls upon a plug, and forces it upon the valve, which suddenly opens, and the air rushes into the barrel of the gun, and by its sudden expansion, propels a ball much in the same manner as gun-powder would do in its place.

293. The *Diving Bell* is an apparatus employed for exploring the depths of the sea. It was formerly made in the shape of a bell, but is now more commonly made square at the top and bottom, the bottom being a little larger than the top, and the sides slightly diverging from above. The material is sometimes cast iron, the whole machine being cast in one piece, and made very thick, so that there is no danger either from leakage or fracture. Sometimes the diving bell is made of planks of two thicknesses, with sheet lead between them. In the top of the machine are placed several strong glass lenses for the admission of light, such as are used in the decks of vessels to illuminate the apartments below.

294. The diving bell depends for its efficacy on that quality of air which is common to all material substances, *impenetrability*; that is, the exclusion of all other bodies from the space it occupies. The principle may be illustrated by depressing a tumbler or jar in water, with the mouth downwards: it will be seen (Art. 285.) that the water will ascend so far as to oc-

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Describe the Condensing Fountain. Cause of the Geysers. Define the Air-Gun. Shew how the force is applied, and how the gun is discharged. Describe the Diving Bell—its shape—material—how illuminated. On what quality of the air does it depend?

›nly a part of the capacity of the vessel, the upper part occupied by air. As the diving bell descends in the the air inclosed in it is subject to its pressure, (which ses with the depth,) and by virtue of its elasticity, it will ıe condensed in proportion to this pressure. Thus at the of about 34 feet, the hydrostatic pressure will be equal to f the atmosphere, and consequently, the air being under a ıre equivalent to that of two atmospheres, it will be condens- › one half its original volume. As the depth is increased, the occupied by the air in the bell will be proportionally dimin-

Seats are furnished for the workmen, and shelves for and various other conveniences. Although at pth of thirty-four feet, the water would occupy ılf the capacity of the vessel, and more or less 'erent depths; yet by means of a forcing pump ıdensing syringe, communicating between the phere above and the machine, through a pipe, ay be thrown in so as to exclude the water y. By the same means fresh air may be con- to the workmen, the portion of air rendered e by respiration, being at the same time suffer- escape by opening a stop-cock in the top of the .ne.

Fig. 71.

The Barometer.

›. Let us take a glass tube, about three feet in , closed at one end and open at the other. We ; tube with quicksilver, and invert it in a vessel same fluid. The column of quicksilver falls to ain height, about 29 or 30 inches, where, after ıng a few times, it remains at rest. The space tube above the quicksilver being void of air or :her substance, it is of course a vacuum, and is y denominated the *Torricellian* vacuum, from Tor- , an Italian philosopher, who first discovered this d of producing a vacuum. Various precautions cessary, in order to preserve this space free from

.t will be the pressure of the water on the enclosed air at the depth ty-four feet? How far will the air be condensed at that depth? ıccommodations are furnished to the workmen? How may air be in so as to exclude the water entirely? How may fresh air be d to the workmen? Show the construction of the Barometer? *is the Torricellian vacuum?* How does the perfection of this *compare with those formed* by other methods?

air or any aeriform substance; when these precautions are taken, this vacuum is the most complete of any that we can command.

296. The column of quicksilver is sustained by the pressure of the atmosphere, on the open mouth of the tube which is immersed in the same fluid;* and it must have the same weight with a column of the atmosphere of the same base, otherwise it would not be in equilibrium with it. We hence arrive at an accurate knowledge of the actual weight and pressure of the air, since it is equal to the weight of a column of quicksilver of the same base, thirty inches in length. The weight of such a cylinder of quicksilver is easily ascertained, and it results, that the pressure on every square inch of surface is, as stated in Art. 289, about 15 lbs. or more than 2000 lbs. upon a square foot. Since different fluids balance each other in opposite columns pressing base to base, when their heights are inversely as their specific gravities, a column of water in the place of the mercury, would stand at the height of about 34 feet. For quicksilver being 13.57 times heavier than water, the latter column must be 13.57 times higher than the other; that is $30 \times 13.57 = 407.1$ inches $= 33.84$ feet.

297. By observing from day to day the height of the column of quicksilver prepared as above, we shall find that it varies through a space of two or three inches, showing that the atmosphere does not always exert the same pressure, but that a given column of the air is sometimes lighter and sometimes heavier. This instrument, therefore, enables us to ascertain the relative weight of the air at any given time, and hence its name *barometer*.† For the purpose of indicating these variations with minuteness and precision, a graduated scale is attached to the barometer, divided into inches and tenths of an inch, and usually extending from twenty-seven to thirty-one inches,—a space which is more than sufficient to comprehend all the natural variations in the weight of the atmosphere.

How is the column of quicksilver sustained? What would be the height of a column of water required to balance the pressure of the atmosphere? What changes occur from day to day in the height of the barometer?

* As young learners sometimes find a difficulty in conceiving clearly how the pressure of the air acts in this case, we subjoin a remark or two. It must be recollected, that any impulse or pressure exerted on the surface of the fluid in the vessel, extends alike to every part of it; and since the fluids act upwards as well as downwards, it is plain that the pressure acts in sustaining the column of mercury in the same manner as though it were applied directly to the mouth of the tube.

† From βαρος *weight*, and μετρον measure.

298. Since the variations of the barometer correspond to the variations in the weight of the air at the same place, and since these are connected with changes of weather, this instrument thus becomes a *weather glass*, and enables us, in certain cases, to foresee changes of the weather. The most uniform indications of the barometer are, that *its rise denotes fair*, and *its fall denotes foul weather*, whatever may be its absolute height. Also a *sudden and extraordinary descent* of the mercury attends, and frequently precedes a *violent wind*.

299. The mean pressure of the atmosphere, as indicated by the barometer, is nearly the same at the level of the sea in all parts of the earth, corresponding very nearly to 30 inches of mercury. This fact has been verified by numberless observations, made with the barometer in both hemispheres, from the equatorial to the polar regions. The following results for several places, in different latitudes, corrected for temperature, elevation above the level of the sea, and the influence of the earth's rotation on its axis are nearly uniform.

	Latitude.	Bar. Pressure.
Calcutta,	22° 35′	29.776
London,	51 31	29.827
Edinburgh,	55 56	29.835
Melville Island,	74 30	29.884

But though the mean pressure of the atmosphere is nearly the same, at the level of the sea, over the whole globe, the extent of the variations to which it is liable, is exceedingly different in different parallels of latitude. At the equatorial regions, the range of the barometer is much more limited than within the polar circles; and in the frigid zones, it is more limited than in the temperate. Within the tropics the fluctuations of the barometer do not much exceed ¼ of an inch, while beyond this space, they reach to 3 inches. The most extensive variations take place between the latitudes of 30° and 60°, being the zone in which the annual changes of temperature and humidity possess the widest range.

300. Shortly after the invention of the barometer, it was observed that the mercury descends, when the instrument is carried to a more elevated situation. The descent is found to be about

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How are these variations indicated? What indications of changes of weather are afforded by the barometer? To what height of the barometer does the mean pressure of the atmosphere in all parts of the world, correspond? *How is the range of the* barometer in the equatorial regions? *how within the polar circles?* how in the middle latitudes?

$\frac{1}{10}$ of an inch for 87 feet. From this observation, we may duce the specific gravity of air compared with mercury or wa for $\frac{1}{10}$ of an inch of mercury has, it appears, the same weigh 87 feet, or 1044 inches, of air. Consequently, 1 inch of mer weighs as much as 10440 inches of air; that is, mercur 10440 times, and water is $\left(\frac{10440}{13.57}=\right)$ 769 times heavier air.

301. As the air pump enables us to investigate the mec ical properties of any portion of air, so the barometer enabl to study the properties and relations of the entire body o air, that is, the atmosphere. By means of these two instrum the following facts are well established.

(1.) *The space occupied by any given portion of air*, (as grains for example,) *is inversely as the pressure.* A w of two atmospheres diminishes the bulk to one half; of atmospheres, to one third; and of one hundred atmosphere one hundredth part of its former bulk.

(2.) As the density is likewise inversely as the space c pied, therefore, *the density is as the pressure.*

(3.) Since air when compressed, endeavors to restore i with a force which is equal to that which compresses it, (when at rest in equilibrium with that force,) therefore, *the ticity is as the density and inversely as the space occupied.* this proposition, the temperature is supposed to remain uni But, the bulk and density of a portion of air remaining the s *the elasticity is as the temperature.* Hence the elasticity may be increased, either by compressing it, or by heating i confined state; and its elasticity may be diminished eith lessening the pressure, or by cooling it. The elasticity of sp is known to be frequently impaired by continual action. is not the case with air. Air has been left for several years much compressed in suitable vessels, in which there was no that could have a chemical action upon it; and afterward removing the unusual pressure, and restoring the same ter ature, the air has been found to recover its original bulk, w shows that the continuance of the pressure had not dimin the elasticity of it in the least perceptible degree.

What do the air pump and the barometer respectively enable us vestigate? To what is the space occupied by any given portion of ai portioned? To what is the density proportioned? How is the ela related to the density and to the space occupied? Also to the ten ture? How may the elasticity of air be increased or diminished? elasticity of air impaired by action?

CHAPTER II.

OF THE ATMOSPHERE.

302. The knowledge now acquired of the properties of elastic fluids, will qualify the learner to enter advantageously upon the study of the entire body of the air, which constitutes the atmosphere. Let us therefore now proceed to consider its *weight*,—its *extent* and *density*,—its relations to *heat and moisture*, giving rise to the various phenomena of Meteorology,—and its relations to *sound*, whence arises the science of Acoustics.

303. The WEIGHT of the entire atmosphere may be easily estimated by means of the barometer; for taking the medium height of the mercury at thirty inches, the weight of the atmosphere is equal to that of a sea of quicksilver, covering the whole earth to the depth of two and a half feet. This would add five feet to the diameter of the globe, and the contents of the whole mass of quicksilver, in cubic feet, would be equal to the difference between the solid contents of the globe, and those of a sphere of a diameter five feet greater. Having the number of cubic feet of quicksilver, we have only to multiply that number by the weight of one foot, and we obtain for the weight of the whole atmosphere, 11,624914,803603,492864 lbs., or more than eleven trillions of pounds, or five thousand billions of tons.

304. Were the atmosphere of equal density throughout, it would be easy to determine its height, since opposite columns of different fluids are in equilibrium, when their heights are inversely as their specific gravities, (Art. 251.) Therefore, as the specific gravity of air is to that of quicksilver, so is the height of the column of quicksilver to the corresponding height of the column of air that balances it.

That is, 1 : 10440 : : 2.5 : 26100 feet=5 miles nearly.

But the atmosphere is very far from being throughout of uniform density. Several causes conspire to produce this result. 1. The different quantities of superincumbent air at different altitudes; 2. The decreasing attraction of the earth in proportion as the square of the distance from its center increases; 3. The influence of heat and cold; 4. The admixtures of vapors

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The Atmosphere.—How may the *weight* of the atmosphere be estimated? What is the actual weight of the whole atmosphere? *Height.*—How determined *were it throughout of the same density*? What causes prevent *the atmosphere from being* throughout of uniform density?

and other fluids; 5. The attraction of the moon and other celestial bodies. That the lower strata of the atmosphere are far more dense than the upper, will be obvious from this consideration, that the portions which rest on the surface of the earth sustain the weight of the whole body of the atmosphere, which, as appears from Art. 303, is immensely great. But the density of air is as the compressing force. (Art. 301.) As we ascend from the earth, the weight sustained is constantly diminished, and the density lessened, according to the following law.

305. *The densities of the air decrease in a geometrical, as the distances from the earth increase in an arithmetical ratio.*

By observations on the barometer at different altitudes, aided by calculation, it is ascertained, that at the height of seven miles above the earth, the air is only one fourth as dense as it is at the surface. Hence, if we take an arithmetical series, increasing by seven, to denote different heights, and a geometrical series whose constant multiplier is one fourth, to denote the corresponding densities, we may easily ascertain the density of the air at any proposed elevation.

Arithmetical series,	7	14	21	28	35	42	49
Geometrical series,	$\frac{1}{4}$	$\frac{1}{16}$	$\frac{1}{64}$	$\frac{1}{256}$	$\frac{1}{1024}$	$\frac{1}{4096}$	$\frac{1}{16384}$

306. From this table it appears, that at the height of twenty-one miles, the air is sixty-four times as rare as at the surface of the earth; at the height of forty-nine miles, sixteen thousand three hundred and eighty-four times as rare; and if we pursue the calculation, we shall find that its rarity at the moderate distance of only one hundred miles, is one thousand millions of times greater than at the earth, and of course would oppose no sensible resistance to bodies revolving in it. De Luc ascended in a balloon to such a height that his barometer fell to twelve inches. Supposing the barometer at the surface to have stood, at that time, at thirty inches, it follows that he must have left three fifths of the whole atmosphere below him; for six inches being one fifth of thirty, twelve inches must be two fifths, and consequently three fifths of the whole must be below. His elevation was upwards of twenty thousand feet. If there were an opening in the interior of the earth, which would permit the air to descend, its density would increase in the same manner as

According to what law does the density of the air descend as we ascend from the surface of the earth? What is its density at the height of seven miles? at the height of 21, 49, and 100 miles? To what degree did the barometer fall in ascending 20,000 feet in a balloon?

it diminishes in the opposite direction. At the depth of about thirty-four miles, it would be as dense as water; at the depth of forty-eight miles, it would be as dense as quicksilver; and at the depth of about fifty miles, as dense as gold.

307. The foregoing law, however, does not afford *exact* data for estimating the density of the air at any given elevation, since the density is affected by the several other circumstances mentioned in Art. 304, which are not here taken into the account. Since the force of attraction diminishes as the square of the distance from the center of the earth increases, this diminution will occasion a corresponding decrease of density. However, as the force of attraction will be very nearly the same at such elevations as the highest mountains, as it is at the general level of the earth, no allowance is made on this account for barometric measurements, except in cases when extreme accuracy is required. Changes of temperature produce a much greater effect, since heat expands and cold contracts the air; and therefore, in estimating altitudes, the state of the thermometer is always to be taken into account, in connexion with the height of barometer. Heat and cold also affect the height of the mercury in the barometer, independently of the pressure of the atmosphere without, and therefore it becomes nesessary to reduce the observations to a fixed standard of temperature.

308. As we ascend from the earth, the temperature of the air constantly diminishes until we arrive at a region of frost, the lower limit of which is called the *term of perpetual congelation*. The heights of the term of congelation for every parallel of latitude from the equator to the north pole, have been computed, partly from observation, and partly from the known mean temperature of each parallel, and the decrement of heat as we ascend in the atmosphere.

It appears, that the height of the region of perpetual frost at the equator is almost three miles; at the parallel of 35°, about two miles; and at the latitude of 54°, about one mile; while at the latitude of 80°, this region approaches very near to the earth, and at the pole it probably comes nearly or quite down to the earth. It is farther to be remarked, that the

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What would be the density of the air in a cave 34, 48, and 50 miles deep? In estimating heights with the barometer, is any allowance made for the diminished force of gravity? Any for changes of temperature? How is the temperature of the upper regions of the atmosphere? What is the term of perpetual congelation? What height is the region of perpetual frost at the *equator*—at the parallel of 35°—and at 80°?

different heights decrease very slowly as we recede from the equator, until we reach the limits of the torrid zone, when they decrease much more rapidly, the maximum being at the parallel of 40°. The average difference of every five degrees of latitude from 30° to 60°, is 1334, while from the equator to 30°, the average is only 509, and from 60°, to 80°, it is only 891. Important meteorological phenomena depend on this fact.

309. As a portion of air rarefied by heat at the earth's surface ascends, the diminishing pressure which it sustains as it rises, has a tendency to enlarge its volume. But on the other hand, an enlargement of volume increases its capacity for heat, and lowers its temperature, which tends to condense it. At a moderate elevation above the earth, the causes operate to keep the air at rest, and thus the heat of the earth is incapable of raising the temperature of the air, except within a moderate distance, beyond which the region of frost prevails, and the cold continues to increase, until it probably reaches, at a comparatively moderate distance from the earth, an intensity almost inconceivable.

Relations of Air to Heat.

310. Air is set in motion by every cause which disturbs its equilibrium. It is more sensible than the most delicate balance, and moves with the slightest inequalities of pressure.

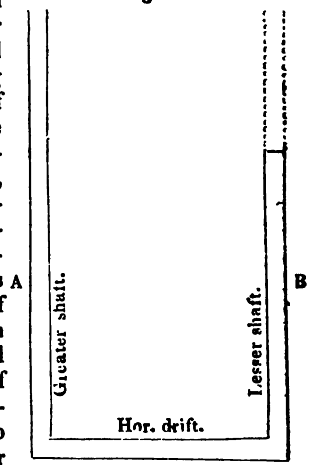
Air is put in motion by *the least change of temperature.* Heat rarefies it, and renders it specifically lighter than the neighboring portions, and it ascends, while colder and denser portions flow in to restore the equilibrium. On the other hand, if air be condensed by cold, it descends, or flows off, until it meets with air of the same density, where it rests. These effects naturally result from the perfect fluidity and elasticity of this substance.

311. An illustration of this principle is seen in the manner in which air circulates in the shaft or pit of a deep mine. Such a circulation is kept up briskly, even amounting sometimes to a strong wind, when two shafts or pits of unequal heights are

How at the pole? Where do the heights decrease most rapidly? What causes combine to confine the heat imbibed at the surface of the earth to the lower regions? How is heat set in motion? What are the respective effects of heat and cold upon air? Illustrate the motions arising from disturbing the equilibrium of the atmosphere by the circulation in a deep mine?

o communicate with each other by means of a horizon- lery called a drift. The earth remains nearly at the emperature summer and winter, while the external air er in summer and colder in winter, than that w.thin the Now were the air within the earth and without, of the lensity, then the air of the afts and of the drift would ι in equilibrio, the longer A, being counterbalanced shorter shaft B, extending to embrace C, a portion of cternal air, to the same as the column A. But sup- summer; then the air in A, ing condensed by the in- ͻ of the colder earth, is ren- specifically heavier, and o- vers the air iu the columns C, the latter consisting of re rarefied than that within rth. Hence, the air will own the longer, and out of orter shaft; and by bring- l parts of the mine into culation, the whole interior ventilated. Again, suppose it winter; then the air in the shaft being warmer and more rarefied than the compound n BC, the latter preponderates, and the air flows in the te direction; namely, down the shorter and out at the shaft. In spring and autumn, when the temperature of nosphere and the mine are nearly equal, the miners com- nuch of the suffocating state of the air.

Fig. 77.



. The contemplation of the motions of the atmosphere arge scale, as they exist in nature, leads to the subject of ; but we may see the same principles exemplified in *ies* and *fire-places.* A chimney may be regarded as a idicular tube, containing a column of air. Since the den- the air is less above than below, and consequently the ınce less at the top than at the bottom of the chimney, ndency of any current of air through the tube is upward, g in the direction in which the resistance is least. When

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n is the external air warmer and when colder than that of the *At what season is the* air of the mine suffocating?

the air of the chimney is rarefied by heat from the fire-place, the cold air from below makes its passage upwards into the partial void, and thus supplies air to the fire to support its combustion, and carries up along with it the smoke and vapors which proceed from the fire. The smoke, it will be remarked, is carried up, mechanically, by the ascending current of hot air; for smoke is itself heavier than air, and sinks or descends when not thus supported.* The *draught* of the chimney, or the strength and velocity of the ascending current, is influenced by several circumstances. (1.) Long chimnies have a stronger draught than short ones, because they present a longer column of rarefied air; but they may be so long as to cool the air too much before it has reached the top, in which case the smoke falls by its greater specific gravity. Long *horizontal* pipes, connected with fire-places or stoves, are apt to smoke, for a similar reason, and, on various accounts, constitute a very ineligible mode of distributing heat. (2.) A narrow throat, opening into a large pipe or funnel, makes a strong draught, because the velocity of the ascending current is thus increased, it being in different parts of the chimney inversely as the area of the section. The throat of the chimney, however, must be wide enough to admit freely all the mixed products of the ascending current, including the rarefied air, smoke, watery vapor, and so on; and, consequently, a wider throat is required for green wood than for dry, and least of all for anthracite coal, where the amount of volatile substances expelled from the fuel is comparatively small. (3.) A fire-place with a low front or breast, has a strong draught, because, in this case, no air can enter the chimney, except such as has felt the influence of the fire, and is thus fitted to keep the chimney warm; whereas, if the throat of the fire-place is high, much of the air that flows into it is cold, and cools the chimney, and of course diminishes the degree of rarefaction in it. Moreover, when the throat is near the fire, it becomes more intensely heated, and thus the degree of rarefaction of the current of air that passes through it is augmented, and its velocity increased. In the structure of fire-places and stoves, it is an important principle, that *as little air as possible should get into the flue of the chimney, except what passes*

Structure of Chimnies.—On what principle does smoke ascend the chimney? Mention the circumstances on which the *draught* depends—the peculiarities of long chimnies—of a narrow throat—of fire places with low fronts. What precaution should be taken respecting the admission of air into the flue of the chimney?

* *This fact* is illustrated by an experiment, suggested by Dr. Franklin, viz. by *blowing the smoke* of a tobacco pipe through water in a tumbler. The smoke, being cooled *by this process*, rests upon the surface of the water.

through the fire; and it is another important principle, in regard to the economy of fuel, that *no more air should traverse the fire than what is necessary to support the combustion.* All the air that passes through the fire, over and above what undergoes decomposition, cools it, and carries a portion of the heat up chimney. It is obvious that the air of an apartment must be denser than that at the top of the chimney, otherwise the current will flow downwards, as is sometimes the case when the room is very close, and the throat of the fire-place so large as to require a great quantity of air to fill the rarefied space, in which case, the air of the room is speedily exhausted. Hence, the advantage, in close apartments, of small fire-places, or stoves which require but a small supply of air.

313. But a much more extensive operation of the same principles is exhibited to us by nature, in the phenomena of WINDS. Rarefaction by heat, and condensation by cold, are the chief causes of winds. Their distinct existence and modes of operation, can frequently be discovered; and, in cases where we can discover neither, we are authorized to infer the presence of such a cause, since it is so constantly connected with the same effects in very numerous examples that daily pass before our eyes, while we are unacquainted with any other adequate causes of the same phenomena. The motion of the air, however, producing a wind, may be merely *relative,* arising from the motion of the spectator. Thus a steam-boat, moving at the rate of sixteen miles an hour in a perfect calm, would appear to one on board to be facing a wind, moving at the same rate in the opposite direction; or if, in the diurnal revolution of the earth on its axis, any point of the earth's surface should move faster than the portion of the atmosphere above it, a relative wind in the opposite direction would be the result. The *direction* of the wind may be modified by various causes, the actual direction being sometimes the *resultant* of two or more currents which meet from different directions, or of several different forces.

314. *Land and sea breezes* afford a striking exemplification of the principle in question. These winds prevail in most maritime countries, but more especially in the islands of the torrid zone, blowing off from the land at night, and towards the

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What amount of air should traverse the fire? What effect has that portion of air which passes the fire undecomposed? When does the current flow down chimney? What is the great cause of Winds? Give examples of a wind that is merely relative. Land and sea breezes—where do they prevail?

land in the day time. If we place a hot stone in a room, (says Dr. Robison,) and hold near to it a candle just extinguished, we shall see the smoke move towards the stone, and then ascend up from it. Now, suppose an island receiving the first rays of the sun in a perfectly calm morning; the ground will become warm, and will rarefy the contiguous air. If the island be mountainous, this effect will be more remarkable; because the inclined sides of the hills will receive the heat more directly. The midland air will therefore be most warmed; the heated air will rise, and that in the middle will rise fastest; and thus a current of air upwards will begin, which must be supplied by air coming in on all sides, to be heated and to rise in its turn; and thus the morning sea breeze is produced, and continues all day. This current will frequently be reversed during the night, by the air cooling and gliding down the sides of the hills, and we shall then have the land breeze.

315. The *trade winds* afford an example of the operation of the same causes on a still greater scale. These winds prevail in the torrid zone and a little beyond it, extending to nearly 30° on both sides of the equator. When not affected by local causes, they blow constantly at the same place, in one and the same direction, throughout the year. Their general direction is from north-east to south-west on the north side of the equator, and from south-east to north-west on the south side of the equator. They owe their origin to the combined agency of two causes, namely, the movement of the air on either side of the equator, northward or southward towards the place of greatest rarefaction, and the westerly tendency arising from the effect of the earth's diurnal rotation on its axis, since they do not instantaneously acquire the greater velocity which the equatorial regions have, in consequence of the earth's revolution on its axis. The duration of the trade winds is variously modified in different parts of the world, but always in such a manner, that they blow towards the point of greatest rarefaction, and receive a relative motion from the effect of the earth's diurnal rotation.

Relations af Air to Moisture.

316. The foregoing atmospheric phenomena arise chiefly from the relations of air to *Heat;* we are next to trace a few

How is their theory illustrated by a hot stone? Is a mountainous, or a plane surface, most favorable to the effect? When does the land breeze *prevail?* The Trade Winds—where do they prevail? How do they *blow?* In what direction? To what two causes do they owe their *origin?*

of the leading phenomena, which result from the relations of air to *Moisture.*

By the action of the sun's heat upon the surface of the earth, whether land or water, immense quantities of vapor are raised into the atmosphere, supplying materials for all the water that is deposited again in the various forms of dew, fog, rain, snow, and hail. Our limits will now allow us to enter largely into Meteorology, under which head the various phenomena of the atmosphere are included; but we shall be able barely to glance at the subject.

317. The leading principle upon which the precipitation of moisture from the atmospere, under any form, depends, is the following:—

The capacity of air for moisture is increased by heat and diminished by cold.*

In other words, air by being heated is rendered capable of *taking up* and *holding* a greater quantity of water in the invisible state, and by being cooled, its power of thus holding water is lessened.

Again, the capacity of air for moisture increases *faster than the temperature*; so that the addition of ten degrees of heat to air already at the temperature of 70°, will increase the capacity for water much more than the same addition would do when made to air at the temperature of 40°. On the other hand, the cooling of hot air diminishes its capacity for moisture much faster than the cooling of air already cold.

318. DEW *is formed when the air comes in contact with a surface in a certain degree colder than itself.* This is the simplest deposition of moisture from the atmosphere. Thus dew is formed copiously on a cup of cold water during summer, par-

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Relations of Air to Moisture.—What effect is produced by the action of the sea on the surface of the earth? How is the capacity of air for moisture affected by heat and cold? Explain the use of the term *capacity.* Explain how the capacity of the air for moisture increases faster than the temperature. How is *Dew* formed? Why is moisture deposited in a vessel of cold water in summer? Why is this fact particularly noticed before a thunder storm?

* The term *capacity* being frequently employed in the physical sciences, it is important for the student to obtain clear and correct views of its meaning. The power of a sponge to hold water, to stow it away in the interior, so as to render it invisible, is the *capacity* of the sponge for water. This capacity is capable of increase or diminution. Take a piece of dry sponge, and soak it in water; as its volume enlarges, its capacity for water increases—remove it from the water, and squeeze it gently; a part of the water runs out—suffer it to expand and it appears nearly dry; squeeze it again, and it becomes wet. Hence we say its capacity is increased by an enlargement of volume, and *diminished by compression.*

particularly before a thunder shower: because then the air is hot, and saturated with moisture, a portion of which it deposits as soon as it is cooled, its capacity for moisture being thus diminished.

It is ascertained by actual observation, that on those nights when copious dews occur, the ground becomes twelve or fourteen degrees colder than the air a few feet above it. Consequently, whenever the air, by circulating over the surface of the ground, comes in contact with this colder surface, it deposits a portion of its moisture upon it. The quantity actually deposited will of course be greater as the difference of temperatures between the air and the ground is greater, and the air is more nearly saturated with moisture.

Dew is found to be deposited on different substances unequally, more on vegetables than on dry sand; very little on bright metallic surfaces, and none at all on large bodies of water, as the ocean. In all cases, however, these surfaces are observed to maintain a corresponding difference in the temperature they acquire, some growing much colder than others equally exposed, while the surface of the ocean remains at the same temperature as the air incumbent on it. The air, therefore, sustains no reduction of capacity by circulating upon it, and no dew is deposited.

219. *Fogs are produced by watery vapor coming in contact with air colder than itself.*

The vapor may be such as is just rising from the ground, or such as before existed in a body of common air that meets and mixes with the colder air. Thus, in a cold morning, smoke proceeds from various moist substances, as from the breath of animals, from a hole in the ice of a river, from wells, and from many other sources. In each case, the vapor meets with cold air, which having so small a capacity for moisture, is unable to hold it in solution, and it is deposited in the form of fog. A striking example of fogs is seen over rivers, particularly in a summer morning, marking out their courses for a great distance. Here, since the temperature of the water changes but little during the night, while the neighboring land, and of course the air over the land, has become cold, the vapor which rises from the river during the night, and meets with cold air, is con-

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What is the temperature of the ground compared with that of the air, on dewy nights? Explain the manner in which dew is deposited on different substances. Why is no dew deposited on the open sea? How are *Fogs* produced? Explain the production of smoke from various *substances* in a cold morning. Explain the cloud of fog that hangs over *rivers.*

densed into a fog. The fogs formed over shoals and sand banks, as the banks of Newfoundland, are deposited from the warm and humid air of the ocean, which is cooled by mixing with the cold air over the banks. Fogs are phenomena of cold climates, and are not so common in hot countries; the air in such situations having too great a capacity for moisture, to permit it to condense into a fog near the surface of the earth.

320. CLOUDS *are dependent on the same principle as fogs, consisting of vapor condensed by the cold of the upper regions.* They are formed over water, or moist places, by vapor rising so high, as to reach a degree of cold sufficient to condense it; or they result from the mixture of warmer with colder air, proceeding always from the warmer portion.

321. RAIN *is produced by the sudden cooling of air, charged with large quantities of watery vapor.*

Suppose two bodies of air, a hotter and a colder portion, both saturated with moisture, to meet; the compound would assume a temperature which was the mean between the two; but the quantity of heat which the colder portion of air would gain, would not increase its capacity so much as that of the warmer body would be diminished, by the loss of the same portion of heat. (Art. 317.) Hence the capacity of the mixture would be less than the average capacities of the separate portions, and consequently water would be deposited. If the separate portions of air are not completely *saturated* with moisture, still the capacity of the mixture may be so much less than that of the constituents, as to render it unable to hold all the water they contained; and in this case, more or less water would be deposited.

322. This view of the general cause of rain, (which is commonly called Hutton's Theory of Rain, from Dr. Hutton, of Edinburg, who first proposed it,) is capable of being confirmed by an extensive induction of facts, by which it would appear, that *variable* winds, favorable to the mixture of air of different temperatures, are accompanied by rain, while *constant* winds are accompanied by dry weather.

How are fogs formed over shoals and sand banks? Are fogs more common in cold or in hot countries? How are *Clouds* formed? Of what do they consist? How is *Rain* produced? Explain its production from the meeting of two opposite currents of air. Which are more *commonly accompanied by rain*, variable or constant winds?

223. HAIL *is produced by the mixture of exceedingly cold air, with a body of hot and humid air.* The cold wind is supposed to be derived from an elevation considerably above the term of perpetual congelation, and to be suddenly transferred to a body of hot and humid air, from which it precipitates the hail. Or it may be supposed to result from a hot wind blowing from the torrid regions into the limits of perpetual frost, and thus having its watery vapor suddenly congealed. Or it may be the product of the meeting of a very cold with a very hot wind. All that the theory requires, in order that hail should be precipitated, is, that *very hot* and *very cold bodies of air* should be mixed in any way whatsoever. Accordingly, hail is found to be most frequent and violent in those regions where hot and cold bodies of air are most easily mixed. Such mixtures are rarely formed in the torrid zone, since there the portion of *cold air* would be wanting; and a similar difficulty exists in the frigid zone, for there the *hot air* is wanting; but in the temperate climate, the heated air of the south, and the intensely cold winds of the north, may be much more easily brought together; and, accordingly, in the temperate zones it is, that hail storms chiefly occur. Even in these climates they are most frequently found in places where such mixtures are most easily formed, as in the south of France, lying, as it does, between the Pyrenees and the Alps, which are covered with perpetual snows, while the intervening country is subject to become highly heated by the summer's sun, or is even visited, especially at a certain elevation, by occasional blasts of the hot winds that cross the Mediterranean.

CHAPTER III.

OF THE MECHANICAL AGENCIES OF AIR AND STEAM.

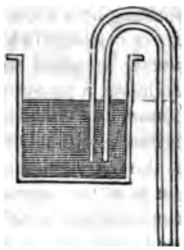
324. In consequence of our power of forming a vacuum, either by the exhaustion of air or by the condensation of steam, and of directing the force with which these elastic substances rush into a void or press towards it, air and steam become important agents or prime movers, in various kinds of machinery. Many of the most useful machines involve in their construction

How is *Hail* produced? Whence is the cold wind derived? Whence the hot wind? Where is hail most frequent and violent? Why rarely found in the torrid zone? Why so frequent in the South of France? *Air and Steam.*—How do they become prime movers in machinery?

the principles of both hydraulics and pneumatics, and therefore we have reserved an account of such machines to the present section.

The Syphon.

Fig. 78.



325. If a tube having two arms, a longer and a shorter, is filled with water, and the mouth of the shorter arm is immersed in water, the fluid will run out through the longer arm until the whole contents of the vessel are discharged. Such a tube is called a *syphon*. It may be filled with the fluid, either by suction or by pouring water into it, keeping the two orifices closed until the shorter arm is immersed. Or, when the syphon is large, each orifice is plugged, and water is poured in through an opening in the top of the bend. The opening being closed, the shorter leg is placed in the cistern, and the plugs removed, the fluid is discharged as usual. The *principle* of the syphon is as follows. The atmosphere presses equally on the mouths of both arms of the tube; but this pressure on each orifice is diminished by the weight of the column of water in the leg nearest to it; consequently, more of the atmospheric pressure is overcome by the longer than by the shorter column, and therefore the *effective pressure*, (or what remains,) is less at the mouth of the longer than at that of the shorter column, and the fluid runs in that direction in which the resistance is least. All this will be obvious by inspecting the figure.

Were the shorter column thirty-four feet in height, it would counterbalance the entire pressure of the atmosphere on the surface of the fluid, and consequently, there would be no force remaining to drive the water forward through the tube. The syphon, therefore, can never raise water to a greater height than thirty-four feet, nor quicksilver higher than about thirty inches. It is obvious, also, that the place of delivery, that is, the mouth of the longer arm, must be at a lower level than the surface of the water in the reservoir; so that this instrument cannot be used for elevating, but only for decanting fluids, or transferring it from one vessel to another. Its chief use is by grocers, in transferring liquors from cask to cask. It is sometimes employed

The *Syphon*—describe it. How may it be filled with fluid? State the principle of the syphon. To what height can the syphon raise water? Why not higher? To what uses is it applied?

in carrying water over a hill, or from a well to a level below the surface of the well.

The Common Suction Pump.

Fig. 79.

326. This pump consists of two hollow cylinders, placed one under the other, and communicating by a valve which opens upwards. The lower cylinder (which has its lower orifice under water) is called the *suction tube*. In the upper cylinder, a piston moves up and down from the bottom to a spout in the side near the top. This cylinder we call the *exhausting tube*. Suppose, at the commencement of the operation, the piston is at the bottom of the exhausting tube in close contact with the valve. On raising it, the air in the suction tube having nothing to resist its upward pressure, lifts the valve and expands, so as to fill the void space which would otherwise be left in the lower part of the exhausting tube. By this means, the air in the suction tube is rarefied, and no longer being a counterpoise to the pressure of the atmosphere on the surface of the well, the latter predominates and forces the water up the tube until enough has been raised exactly to counterbalance the excess of the elasticity of the external air above that of the tube. As the piston descends, the air below it is prevented from returning into the suction pipe by the valve which closes on its mouth, but escapes through a valve in the piston itself, opening upwards in the same manner as in the barrels of the air pump. The piston being raised again, the column of water ascends still higher, until it makes its way through the valve into the exhausting pipe. Then as the piston descends, the water opens its valve, and gets above the piston, and is lifted to the level of the spout, where it is discharged.

The principle of the suction pump may therefore thus be enunciated:

The water is raised into the exhausting pipe by the pressure of the atmosphere, and thence lifted to the level of the spout by means of the piston.

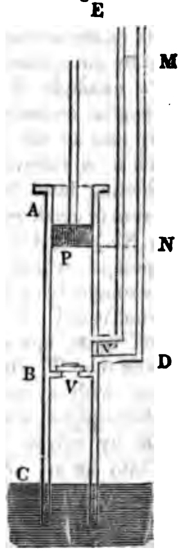
Common Suction Pump—describe it. What are the two cylinders *respectively* called? Explain its operation. Enunciate the principle of the pump.

Since a column of water thirty-four feet in height, in the suction tube, would counterbalance the entire pressure of the atmosphere on the surface of the well, no force would remain to urge the column any higher, and therefore the valve at the top of the suction tube, must be less than thirty-four feet above the well.

327. It is evident that the same force is expended in raising water by means of the pressure of the atmosphere, as when the force is applied directly. We lift upon the atmosphere, instead of lifting directly upon the column of water. This method of raising water from a well, is frequently more convenient than by a simple bucket, but the expenditure of force is the same in both cases.

The Forcing Pump.

Fig. 80.



328. A cylinder ABC (Fig. 80.) is placed with its lower end C in the reservoir. It has a fixed valve at V, opening upwards, and a solid piston without a valve, playing air tight in the upper barrel AB. It is connected with another barrel DE by a valve V′ opening upwards and outwards. The tube DE is carried to whatever height it may be necessary to elevate the water. Let us suppose that the solid piston P is in contact with the valve V, and that the water in the lower barrel is at the same level C with the water in the reservoir. Upon raising the piston, the air in BC will be rarefied, and the water will ascend in BC exactly as in the suction-pump. Upon again depressing the piston, the air in PV will be depressed, and it will force open the valve V′, and escape through it. The process, therefore, until water is raised through V into the upper barrel, is precisely the same as for the suction pump; the valve V′ taking the place of the piston-valve in that machine. Now, let us suppose that water has been elevated through V, and that the space PV is filled with it. Upon depressing the piston, this water, not being permitted to return

How high can the pump raise water? Do we gain any force by means of the pump? *Forcing Pump*—describe it.

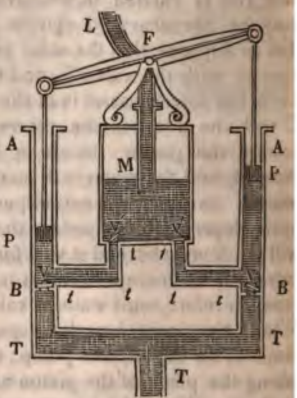
through V, is forced through V′, and ascends in the tube DE. By continuing the process, water will accumulate in the tube DE, until it acquires the necessary elevation, and is discharged. Or, to enunciate the principle of this machine in general terms—

In the forcing pump, the piston has no valve, but the water being elevated into the exhausting tube, as in the suction pump, it is then forced, by the descent of the piston, into the ascending pipe through a valve placed in the side and at the bottom of the exhausting tube.

329. In forcing pumps, since the power is applied by separate impulses, the water would issue in jets, were not some contrivance adopted to equalize its flow from the tube. This purpose is effected by means of an air vessel, in which a portion of condensed air is made the medium of communication. The force imparted by successive blows of the piston is first received by this confined body of air, and this, by its elasticity, reacts on the surface of the water in the air vessel, and forces it out by the conducting pipe or hose.

An example of this is afforded in the *Fire Engine.* The fire engine consists of two forcing pumps, which throw the water into an air vessel, from which it is thrown out of the conducting hose by the elastic pressure of condensed air. Thus (Fig. 81.) AB, AB are two forcing-pumps, whose pistons PP are wrought by a beam whose fulcrum is at F; VV are valves which open upwards from a suction tube T, which communicate with a reservoir; *t t* are force-pipes, which communicate by valves V′V′, opening into an air vessel M. A tube L is inserted in the top of this vessel, terminating in a leathern tube or hose, through which the water is forced by the pressure of the air confined

Fig. 81



Enunciate its principle. What is the use of the air vessel in the forcing pump? Describe the Fire Engine.

in M, which, in consequence of its elasticity, acts nearly uniformly on the surface of the water, and forces it through the hose in a continual stream.

The Steam Engine.

330. It belongs to Chemistry to investigate the properties of steam, and to Natural Philosophy to apply it as a mechanical agent. The Steam Engine is the fruit of the highest efforts of both these sciences, and the most valuable present ever made by philosophy to the arts. As it is impossible clearly to understand the principles and construction of this engine without a knowledge of the properties of steam, on which they depend, we subjoin an account of a few of its leading properties, referring to chemical authors for a more detailed view of this subject.

331. The great and peculiar property of steam, on which its mechanical agencies depend, is *its power of creating at one moment a high degree of elastic force, and losing it instantaneously the next moment.* This force, acting on the bottom of the piston which moves in the main cylinder, raises it, and fills the space below it with steam. The steam is suddenly condensed, and hence no obstacle is opposed to the descent of the piston, but it is readily forced down again by steam acting from above. This alternate motion of the piston, the rod of which is connected with the working beam, is all that is required in order to communicate motion to all parts of the engine.

332. *The elastic force of steam depends on its temperature and density conjointly; and the temperature necessary to its production depends upon the pressure incumbent upon the water during its formation.* The reason why water boils at the temperature of 212° is, that at that temperature, the vapor acquires just elasticity sufficient to overcome the atmospheric pressure. Hence, steam produced at the temperature of boiling water, has a force equal to the pressure of the atmosphere. When formed at a lower temperature, its elasticity diminishes in a

Steam Engine.—What part of it belongs to Chemistry, and what to Natural Philosophy? What is the peculiar property of steam on which its mechanical agencies depend? How does the force operate? On what does the elastic force of steam depend? Why does water boil at the temperature of 212°? How is the elasticity of steam produced at low temperatures?

geometrical ratio, and increases in the same ratio when it is formed at a higher temperature. Water boils, or is converted into vapor, at a temperature less than 212°, on high mountains, or under the receiver of an air pump, or in other situations where the pressure of the atmosphere is diminished; and in a *vacuum* the boiling point of water is as low as 72°.

333. *Heat rapidly augments the elasticity of steam by increasing its density.* If we introduce a few grains of water into a flask, and place it over the fire, the water will soon be converted into steam, which will expel the air of the vessel and fill its whole capacity. If we now close the orifice of the flask and continue the heat, the steam will increase in elastic force in the same manner as air would do under similar circumstances, which is at a comparatively moderate rate, so that it might be heated *red hot* without exerting any very violent force. If, however, the vessel is partly filled with water, and the heat is continued as before, then the elastic force is rapidly augmented, and becomes at length so great as to burst almost any vessel that can be provided; for every new portion of vapor that is raised from the surface of the water, adds to the density of that which was before in the vessel, and proportionally increases its elasticity. In the experiments of Mr. Perkins, a confined portion of steam, not in contact with water, was heated to the temperature of 1400°, and still its pressure did not exceed that of five atmospheres; but, by injecting more water, although the temperature was lessened, the elastic force was gradually increased to one hundred atmospheres.

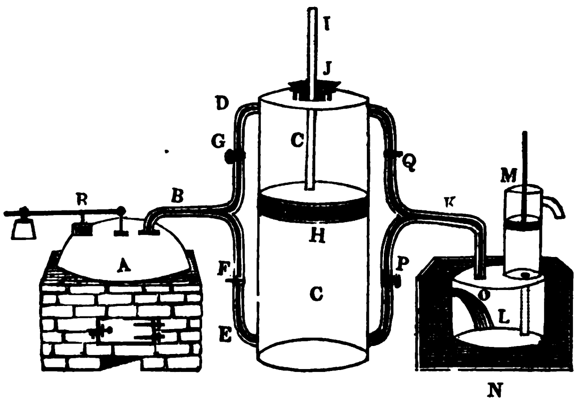
334. *The space into which a given quantity of water is expanded in becoming steam, depends upon the temperature, and of course upon the degree of pressure at which it is formed.* Water converted into steam at the temperature of 212°, expands nearly one thousand and seven hundred times; but at the temperature of 419°, it expands but thirty-seven times. According to Dr. Thomson, at a temperature not much higher than 500°, steam would not much exceed double the bulk of the water from which it is generated. The expansive force of such steam

In what situations does water boil at a lower temperature than 212°? In what manner does heat augment the elasticity of steam? How is the elasticity of steam affected when heated in a close vessel over water, and how when heated by itself? Into what space does water expand in becoming steam? How is this space affected by increasing the pressure? What would be the space occupied at the temperature of 500°?

would be truly formidable. It would, when it issued into the atmosphere, suddenly expand six hundred and fifty times. We do not know at what temperature water would become vapor without any increase of volume, but we can estimate that it would then support a column of mercury three thousand two hundred and forty-three feet (or more than half a mile) high, and would exert a pressure of nearly *twenty thousand pounds* on every square inch.

335. The difficulty of understanding the construction and principles of the steam engine, (as is the case also with many other machines where the parts are numerous,) is greatly enhanced by the variety of accidental trappings or appendages that are employed about the machine to perform subordinate offices. As these render the comprehension of the leading principles difficult, when the explanation is attempted from the engine itself, so these inferior parts are often so multiplied in diagrams as greatly to obscure the representation. We shall begin our explanation with a diagram which presents the naked

Fig 82*.



principles, divested of all unnecessary appendages. The chief parts of the engine are the *boiler* A, the *cylinder* C, the *con-*

How high a column of mercury would steam support when heated under such a pressure as not to exceed the volume of water? Explain the construction of the steam engine from figure 82. What are the chief parts?

* *From Jones's Conversations on Chemistry, a work which contains a very luminous view of the elementary principles of the steam engine.*

denser L, and the *air-pump* M. B is the *steam-pipe*, branching into two arms communicating respectively with the top and bottom of the cylinder; and K is the *eduction-pipe*, formed of the two branches which proceed from the top and bottom of the cylinder, and communicate between the cylinder and the condenser. N is a cistern or well of cold water in which the condenser is immersed. Each branch of pipe has its own valve, as F, G, P, Q, which may be opened or closed as the occasion requires.

336. Suppose, first, that all the valves are open, while steam is issuing freely from the boiler. It is easy to see that the steam would circulate freely through all parts of the machine, expelling the air, which would escape through the valve in the piston of the air-pump, and thus the interior spaces would be all filled with steam. This process is called *blowing through*; it is heard when a steam-boat is about setting off. Next the valves F and Q are closed, G and P remaining open. The steam now pressing on the cylinder forces it down, and the instant when it begins to descend, the stop cock O is opened, admitting cold water, which meets the steam as it rushes from the cylinder, and effectually condenses it, leaving no force below the piston to oppose its descent. Lastly, G and P being closed, F and Q are opened, the steam flows in below the piston and rushes from above it into the condenser, by which means the piston is forced up again with the same power as that with which it descended. Meanwhile the air-pump is playing, and removing the water and air from the condenser, and pouring the water into a reservoir, whence it is conveyed to the boiler to renew the same circuit.

337. Among the different forces which may be employed to move machinery, such as animal strength, water, wind, and steam, the last is the most manageable of all, and therefore, for almost every purpose, the most convenient of all powers that are under the control of man. But whether, in a given case, we shall employ steam power, or one of the other forces, as water power for example, may depend on the comparative economy of the two forces. A water fall, near at hand, may furnish us with the required power, cheaper than we can produce it artificially from steam. In the earlier forms of con-

Show how the steam operates in the ascent and descent of the piston? *How does steam compare with other forces in manageableness? How in economy?* What formerly diminished the usefulness of this machine?

tion adopted in the Steam Engine, so much of the steam wasted by injudicious management, as greatly to diminish sefulness of this Engine, and to render it in most cases a eligible force for carrying machinery than animal strength ater. The modern improvements in the Steam Engine consisted, mainly, in preventing this waste of steam, and ›urse in economizing the amount of fuel required to pro- the power. Previous to the year 1763, when Watt began improvements on the steam engine, not less than *three hs* of the steam produced in the boiler was wasted.

8. The greatest improvement introduced by Mr. Watt, isted in performing the condensation in a separate vessel, Fig. 82.) whereas the previous method was to admit a jet ›ld water into the cylinder (CC) itself, which cooled the e apparatus; and when steam was admitted again from oiler, a great quantity of it was consumed in heating the d surface up to the boiling point, which must be done be- the steam could have sufficient elasticity to move the ma- ery. Various subordinate contrivances were also employ- ith the view of promoting convenience or economy, the iple of which will be understood from the description of nnexed figure, which represents the steam engine in its improved state.

9. A. The BOILER, containing a large quantity of water, which is constantly renewed as fast as portions are converted into steam.

B. The STEAM PIPE, conveying the steam to the cylinder, having a steam-cock *b* to admit or exclude the steam at pleasure.

C. The CYLINDER, surrounded by the *jacket c c*, a space kept constantly supplied with hot steam, in order to keep the cylinder from being cooled by the external air.

D. The EDUCTION PIPE, communicating between the cylinder and the condenser.

E. The CONDENSER, with a valve *e*, called the *Injection cock*, admitting a jet of cold water, which

what have consisted the modern improvements of the steam en- What portion of the steam was formerly wasted? In what con- the great improvement of Watt? Describe the old method. Give cription of the various parts in order from the figures.

meets the steam the instant the latter enters the condenser.

F. The AIR-PUMP, which is a common suction pump, but is called the *air-pump* because it removes from the condenser, not only the water, but also the air and steam that escapes condensation.

G. G. The COLD WATER CISTERN, which surrounds the condenser and supplies it with cold water, being filled by

H. The COLD WATER PUMP.

I. The HOT WELL, containing water from the condenser.

K. The HOT WATER PUMP, which conveys back the water of condensation from the hot well to the boiler.

L. L. LEVERS, which open and shut the valves in the channel between the steam pipe, cylinder, eduction pipe, and condenser; which levers are raised or depressed by projections attached to the piston rod of the condenser.

M. M. Apparatus for PARALLEL MOTION. By this contrivance the piston rod is made to move in a right line, although the end of the working beam moves in the arc of a circle.

N. N. The WORKING BEAM.

O. O. The GOVERNOR. This consists of two heavy balls, suspended from a perpendicular shaft, in such a manner as to be capable of falling close to the side of the shaft when at rest, but when made to revolve, they recede from it by the centrifugal force. Now, by connecting the governor with the fly wheel, it is made to participate of the common motion of the engine, and the balls will remain at a constant distance from the perpendicular shaft, so long as the motion of the engine is uniform; but whenever the engine moves faster than usual, the balls will recede farther from the shaft, and by raising a valve connected with the boiler, will let off such a portion of the force as to reduce the speed to the rate required.

P. The Crank. This, when the end of the working beam, to which it is attached, descends, turns the fly wheel half round, and when it rises, completes the revolution of the wheel.

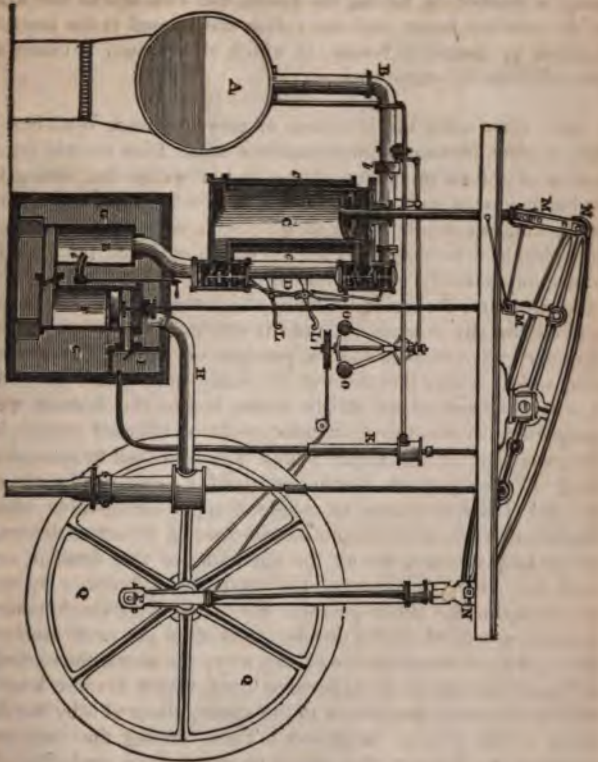


Fig. 83.

Q. Q. The Fly Wheel. The motion of the piston, being communicated first to the Working Beam, and thence to the crank, is finally received by the Fly Wheel, which, by its inertia, as explained in Art. 193. renders the force uniform. The main shaft or axis to which the fly wheel is attached, receiving thus a uniform rotation, motion may be transferred from it to every kind of machinery.

weight or quantity of matter,—and its *tension*. The tone becomes more acute as we increase the tension, or diminish either the length or the weight. The operation of these several circumstances may be seen in a common violin. The pitch of any one of these strings is raised or lowered by turning the screw so as to increase or lessen its tension; or, the tension remaining the same, higher or lower notes are produced by the same string, by applying the fingers in such a manner as to shorten or lengthen the string which is vibrating; or, both the tension and the length of the string remaining the same, the pitch is altered by making the string larger or smaller, and thus increasing or diminishing its weight.

345. *The vibrations of a string, fixed at both ends, are performed in equal times, whether the length of the vibrations be greater or smaller.*

Upon this uniformity in the times of vibration depends the *uniformity of tone;* for if we employ a string of unequal thickness, and consequently one whose vibrations are performed in different times, the sound is confused and variable, and any other mode by which we destroy the isochronism, produces a similar effect. The same law has been found to extend to all other cases of musical sounds ; and, therefore, we may conclude, that *isochronism in the vibrations of sonorous bodies, is essential to their producing musical sounds.*

346. In *wind instruments,* a column of confined air itself is the vibrating body; and here the vibrations are longitudinal instead of lateral, as is the case with strings. That it is really the air which is the sounding body in a flute, organ pipe, or other wind instruments, appears from the fact, that the materials, thickness, or other peculiarities of the pipe, are of no consequence. A pipe of paper and one of lead, glass, or wood, provided the dimensions are the same, produce, under similar circumstances, exactly the same tone as to *pitch.* If the *qualities* of the tones produced by different pipes differ, this is to be attributed to the friction of the air within them, setting, in feeble vibration, their own proper materials. The class of bodies vibrating *longitu-*

What effect has it to increase the tension—or to shorten the string—or to increase its size? How are the times of the vibrations of a string when fixed at both ends? Upon what depends uniformity of tone? To what is isochronism in the number of vibrations essential? In *wind instruments* what is the vibrating body? Does the nature of the material, or its thickness, make any difference?

dinally, is not only more diversified in its powers than the other classes of sounding bodies, but also more extensive in the range of substances which it comprehends.

347. The different *pitch* of bodies vibrating longitudinally, and free at both extremities, depends on four circumstances, viz. their elasticity, the temporary rate at which their elasticity is increased by condensation, their length, and their specific gravity, the tone of a body being more acute, according as the elasticity, and the rate of its increase by condensation, are greater, or the length and specific gravity less. The *length* of the sonorous body is almost exclusively the only one of these circumstances which we have completely in our power; and with regard to ordinary wind instruments, and all musical instruments where common air is the vibrating body, the length is the circumstance of most importance, since the elasticity, rate of condensation, and specific gravity are then nearly constant quantities. The change of specific gravity, however, to which the air is subject in consequence of changes of temperature, materially affects the pitch of wind instruments. The frequency of vibration of a column of air is found to be increased about $\frac{1}{33}$, by an elevation of 30° Fahrenheit. Thus, the tone of an organ has been found to be higher in summer than in winter; and flutes and other wind instruments become gradually more acute as the included air is heated by the breath.

348. If a *bell* be struck by a clapper on the inside, the bell is made to vibrate. The base of the bell is a circle; but it has been found that, by striking any part of the circle on the inside, that part flies out, so that the diameter which passes through this part of the base, will be longer than the other diameters. The base is changed by the blow into the figure of an ellipse, whose longer axis passes through the part against which the clapper is thrown. The elasticity of the bell restores the figure of the base, and again elongates the bell in a direction opposite to the former; and the two elliptical figures thus alternate with each other, growing smaller and smaller, like the vibrations of a pendulum when the moving force is withdrawn, until the sound dies away. We may be convinced by our senses, that the parts of the bell are in a vibratory motion while it sounds. If we lay the hand

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State the *four* circumstances on which the pitch of bodies vibrating longitudinally depends? Which of these can we control? How much is the frequency of vibration of a column of air increased by raising the temperature 30°? How exemplified in the organ, flute, &c.? What change of figure does a bell undergo when struck?

ntly upon it, we shall feel this tremulous motion, and even be le to stop it; or if small pieces of paper be put upon the bell, vibrations will set them in motion.

We may conceive the bell to be formed of an infinitude of ngs, placed one above another, from the base to the highest int. The rings situated nearer to the base, having a greater rcumference, tend to perform their vibrations more slowly, hile the rings nearer to the summit, whose circumferences are naller, tend to produce vibrations oftener. These sounds will coalesce as to produce a mixed sound, intermediate between ose of the higher and lower rings.

Propagation of Sound.

349. AIR is, in general, the medium of sound. A bell struck ıder the receiver of an air pump, gives a feebler and feebler und, as the exhaustion proceeds, until, when the rarefaction carried to a certain extent, it emits no sound at all. Hence, the summit of high mountains, where the air is naturally rare, und ought to be weaker than at the general level of the rth; and such is found to be the fact. Saussure relates that on the top of Mount Blanc, the firing of a pistol made a report louder than that of a child's toy-gun. A fact mentioned by avellers in Alpine countries is explained on this principle. hey see distinctly a huntsman on a neighboring eminence, and serve the flashes of his gun, but can scarcely hear the report, en when comparatively near them.

350. The agency of air as the medium of sound may be iefly expressed thus:

Air receives from sounding bodies vibrations, which it commu-cates to the organs of hearing.

In an open space, and in a serene atmosphere, sound is prop-gated from the sounding body in all directions. Sounds, even e most powerful, when thus transmitted freely through the air, minish rapidly in force, as they depart from their sources, and ithin moderate distances wholly die away. What *law* this

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What sensation is felt on applying the hand to a bell while ringing? Sup-se the bells formed of rings. *Propagation of Sound.*—What is the or-nary medium of sound? Case of a bell under the receiver of an air mp—sound on the top of a high mountain. State the agency of air in e production of sound. Is the law by which sound increases at a distance termined?

diminution follows, is not yet ascertained; and is, indeed, in the present state of Acoustics, incapable of determination. Some writers have supposed that sound follows the common law of emanations radiating from a center, and, consequently, that its intensity at different distances from its source varies inversely as the square of the distance; but we can estimate the force of sounds by the ear alone; an instrument of comparison whose decisions on this point vary with the bodily state of the observer, and whose scale expresses no definite relation but that of equality. Though sound has in general, at its origin, a tendency to diffuse itself in all directions, it is sometimes more propogated in one direction than in others. A cannon seems much louder to those who stand immediately before it, than to those who are placed behind it. The same fact is illustrated by the speaking trumpet; the person to whom the instrument is directed, hears distinctly the words spoken through it, while those who are situated a little to one side, hardly perceive any sound.

351. Sound is in a great measure intercepted by the intervention of any solid obstacle between the hearer and the sonorous body. Thus, if while a bell is sounding, houses intervene between us and the bell, we hear it sound but faintly compared with what we hear after we have turned the corner of the building. From this fact sound would seem to be propagated in straight lines. If, however, we speak through a tube, the voice will be wholly confined by the tube, and will follow its windings however tortuous; hence we infer, that sound is propagated, not in right lines like radiant substances, as heat and light, but in *undulations* after the manner of waves, such as follow when a stone is thrown into still water.

352. Though air is the most common medium of sound, yet it is not the only medium. Various other bodies, both solid and fluid, are excellent conductors of sound; and the fainter sound of the bell when buildings intervene, as in the case supposed, arises from the fact that *sound passes with difficulty from one medium to another*. If a log of wood is scratched with a pin at one extremity, a person who applies his ear to the other extremity will hear the sound distinctly, and when a long pole of wood is applied at one end to the teeth, the ticking of a watch may be heard at the other end, at a much greater distance, than when there is

Does it spread equally in all directions? How is sound affected by the *intervention* of an obstacle? also by passing out of one medium into another? Is air the only medium of sound? Examples of the transmission of sound through solid bodies.

no medium of communication but the air. The motion of a troop of cavalry is heard at a great distance by applying the ear close to the ground, and it is well known that dogs by this method first discover the approach of a stranger.

353. *The* VELOCITY *of sound is progressive.* Thus, when a gun is fired at a distance from us, we perceive the flash some time before we hear the report. Thunder follows the lightning at a perceptible interval, although they are known to be cotemporaneous events. If a gun be fired at a certain known distance, and we observe the interval between the flash and the report, we may obtain the rate at which sound passes, that is, the velocity of sound. Many years since, Dr. Derham made a number of accurate and diversified experiments on this subject, and fixed the velocity of sound at 1142 feet per second. The mean of a great number of experiments gives the average velocity of 1130 feet per second; but the velocity as determined by Derham, namely, 1142 feet per second, is that which has been generally admitted as the standard. Since, however, the transmission of sound depends on the elasticity of the medium, (Art. 347.) causes which affect the elasticity, likewise affect the velocity of sound. Thus, the velocity is a little greater in warm than in cold air, and consequently is somewhat influenced by climate.

354. *Sound moves with a uniform velocity;* that is, it passes over equal spaces in equal times. This important fact was first ascertained by Derham, who found that it held good whether the sound were strong or feeble, whether it proceeded from a hammer or a cannon: in short, that neither the strength nor the origin of the sound made any difference. M. Biot caused several airs to be played on a flute at the end of an iron pipe 3120 feet long, and the notes were distinctly heard by him at the other end, without the slightest derangement in the order or quality of the sounds. The velocity of sound, however, when transmitted through the air, is slightly influenced by the strength and direction of the *wind.* Dr. Derham found that when the wind is blowing in the direction of the sound, its velocity must be added to the standard velocity of sound, and must be subtracted from it when opposed to it. A *transverse* wind does not affect the velocity of sound in the slightest degree.

What is the velocity of sound per second? Is the velocity of sound uniform? Recite the experiment of Biot. What effect has the wind upon the velocity of sound? Does a transverse wind affect it?

355. From a knowledge of the velocity of sound, the *distance* of a sounding body may be estimated. Thus, if the interval between seeing a flash of lightning and hearing the thunder, be six seconds, the distance of the cloud is $6 \times 1142 = 6852$ feet, or $1\frac{3}{10}$ miles. *The air is a better conductor of sound when humid than when dry.* Thus a bell is heard better just before a rain; and this fact lends some countenance to an opinion of the ancients, that sound is heard better by night than by day. Humboldt was particularly struck with this fact, when he heard the noise of the great cataracts of Oronoco, which he describes as three times greater in the night than in the day. The *distance* to which sound may be heard, will of course vary with its force, and various other circumstances which are incapable of being reduced to an exact law. Volcanoes, in South America, have sometimes been heard at the distance of three hundred miles; and naval engagements have been heard at the distance of two hundred miles. The unassisted human voice has been heard from Old to New Gibraltar, a distance of ten or twelve miles, the watchword *All's Well* given at the former place being heard at the latter. Sounds are heard to a much greater distance over water than over land, and farther on smooth than on rough surfaces.

356. *Liquids are good conductors of sound.* Indeed, sound is conveyed with far greater velocity in water than in air, and this too in consequence of its greater elasticity; for, since water has been found by Perkins and others, capable of compression and of restoring itself when the compressing force is removed, it is to be accounted not only elastic, but as exceeding aeriform bodies in elasticity, in proportion as the force required to compress it is greater. Dr. Franklin having plunged his head below water caused a person to strike two stones together beneath the surface and heard the sound distinctly at the distance of more than hal[f] a mile. By similar experiments, it has been ascertained, that though water is a much better conductor of sound than air, ye[t] the sound is greatly enfeebled by passing out of one mediu[m] into the other.

357. *Solid substances convey sound with various degrees of fa[-] cility, but in genaral much better than air, and as well or even be[tter]*

How can the distance of the sounding body be estimated? How do[es] moisture affect the conducting power of the air? To what distance hav[e] volcanoes, cannon, and the human voice been respectively heard? Wh[at] is the conducting power of liquids? How does water compare in th[is] respect with air? State the experiment of Dr. Franklin upon the aud[i-] bility of sounds under water. What is the conducting power of solids?

er than fluids. By placing the ear against a long dry brick vall, and causing a person at a considerable distance to strike t *once* with a hammer, the sound will be heard *twice*, because the vall will convey it with greater rapidity than the air, though each will bring it to the ear. The rate at which *cast iron* conducts sound, was ascertained by M. Biot in the following nanner. He availed himself of the laying of a series of iron pipes to convey water to Paris. The pipes were about eight feet in length, and were connected together with small leaden rings. A bell being suspended within the cavity, at one end of the train of pipes, on striking the clapper at the same instant against the side of the bell, and against the inside of the pipe, two distinct sounds successively were heard by an observer stationed at the other extremity. With a train of iron pipes two thousand five hundred and fifty feet, or nearly half a mile in length, the interval between the two sounds was found from a mean of two hundred trials, to be 1.79 seconds. But the transmission of sound through the internal column of air, would have taken 2.2 seconds; which shows that the sound occupied only .41 of a second in passing through the metal. From more direct trials, it was concluded that the exact interval of time, during which the sound performed its passage through the substance of the train of pipes, amounted to only the .26 of a second, showing that iron conducts sound about ten times as rapidly as air does. If a string be tied to a common fire shovel, and the two ends of the string be wound round the fore fingers of each hand, and the fingers be placed in the ears, on striking the bottom of the shovel against an andiron or other solid body, very deep and heavy tones will be heard, and the vibrations of the metal will be clearly perceived.

The great power of solid bodies to conduct sound is exemplified in *earthquakes*, which are heard almost simultaneously in very distant parts of the earth. *Musical boxes* sound much louder when placed on a table or some solid support, than when the air affords the only conducting medium. It is easy to ascertain whether a kettle boils, by putting one end of a stick or poker on the lid, and the other end to the ear: the bubbling of the water, when it boils, appears louder than the rattling of a carriage in the streets. A slight blow given to the poker, of which one end is held to the ear, produces a sound which is even painfully loud.

How was the conducting power of *cast iron* ascertained by Biot? State the experiment with a fire shovel. How is the conducting power of the earth *exemplified in earthquakes?* How to ascertain when a kettle of water is boiling?

358. A physician of Paris introduced into medical practice an instrument, depending on the power of solid bodies to conduct sound, called the *Stethoscope*, the object of which is to render audible the actions of the heart and the neighboring organs. It consists of a wooden cylinder, one end of which is applied firmly to the breast, while the other end is brought to the ear. By this means, the processes that are going on in the organs of respiration, and in the large blood vessels about the heart, may be distinctly heard; and it is said that the stethoscope, when skillfully used, "becomes the means of ascertaining some diseases in the chest, almost as effectually as if there were convenient windows for visual inspection."

Reflexion of Sound.

359. Sounds are *reflected* by hard bodies, producing the well known phenomenon called an ECHO. If a straight line be drawn from the sounding body to the reflecting surface representing the course of the sound before reflexion, and another straight line be drawn from the reflecting surface, in the direction of the sound after reflexion, these two lines will make equal angles with that surface; that is, when sound is reflected, *the angle of reflexion is equal to the angle of incidence.* The surfaces of various bodies, solids as well as fluids, have been found capable of reflecting sounds, viz. the sides of hills, houses, rocks, banks of earth, the large trunks of trees, the surface of water, especially at the bottom of a well, and sometimes even the clouds. It is therefore evident, that in an extensive plain, or at sea, where there is no elevated body capable of reflecting sounds, no echo can be heard. It is hence easy to see why the poets, who convert Echo into an animated being, place her habitation near mountains, rocks, and woods. An echo is heard when a person stands in a position to hear both the original and the reflected sound; and the interval will be greater or less according to the distance of the reflecting surface from the sounding body and from the hearer, and hence the interval may be made a measure of the distance. If the sound of the voice returns to the speaker in two seconds, the distance of the reflecting surface is one thousand one hundred and forty-two feet, and in that proportion for other intervals. Thus the breadth of a river may be ascertained

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What is the structure and principle of the Stethoscope? *Reflexion of Sound.*—How are the lines of direction of sound before and after reflexion? What surfaces have been found capable of reflecting sound? Why are not echoes heard at sea? How must one be situated in order to hear an echo? How may distances be estimated by echoes?

when there is an echoing rock on the farther shore. A perpendicular mountain's side, or lofty cliffs, such as frequently skirt the sea coast, sometimes return an echo of the discharge of artillery, or of a clap of thunder, to the distance of many miles. The number of syllables that can be pronounced in half the interval, will be repeated distinctly; but a greater number would be blended with the commencement of the echo.

360. The furniture of a room, especially the softer kind, such as curtains or carpets, impairs the qualities of sound by presenting surfaces unfavorable to vibrations. A crowded audience has a similar effect, and increases the difficulty of speaking. Halls for music, or declamation, should be constructed with plain bare walls. Alcoves, recesses, and vaulted ceilings, produce reverberations, which often greatly impair the distinctness of elocution. Indeed, the qualities of a room, in regard to sound, are modified by so many circumstances, that the science of acoustics is worthy of more attention from the architect than it has generally received. Plane and smooth surfaces reflect sound without dispersing it; convex surfaces disperse it, and concave surfaces collect it. The concentration of sound by concave surfaces, produces many curious effects both in nature and art. There are remarkable situations where the sound from a cascade is concentrated by the surface of a neighboring cave, so completely, that a person accidentally bringing his ear into the focus, is astounded by a deafening noise. Sound issuing from the center of a circle, is, by reflexion, returned to the center again, producing a very powerful echo. Such effects are observed in the central parts of a circular hall. An elliptical apartment conveys sound very perfectly from one focus to the other. A whisper uttered by a person in one focus of such a chamber, will be audible to a person in the other focus, though not heard by persons between.

361. The rolling of thunder has been attributed to echoes among the clouds; and that such is the case has been ascertained by direct observation on the sound of cannon. Under a perfectly clear sky, the explosion of guns is heard single and sharp, while, when the sky is overcast, or when a large cloud comes over head, the reports are accompanied by a con-

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What effect has the furniture of a room upon the quality of sound? How do plane, convex, and concave surfaces, respectively reflect sound? How is the sound of a cascade sometimes concentrated? When sound issues from the *center of* a circle, how is it reflected? How from the *focus of an ellipse?* What causes the *rolling of thunder?*

tinued roll, like thunder, and occasionally a double report arises from a single shot. The continued sound of distant thunder, which is sometimes prolonged for many seconds, is not always owing to reverberation, but frequently arises simply from the different distances of the same flash. Although the progress of a flash of lightning through the air were absolutely instantaneous, still, if its path were in a line that would carry it farther from the ear in one place than in another, there would be a corresponding difference in the times at which the sound generated in different portions of the path would reach the ear. Herschel observes, that if (as is almost always the case) the flash be zigzag, and composed of broken, rectilinear, and curvilinear portions, some concave, some convex to the ear; and especially, if the principal trunk separates into many branches, each breaking its own way through the air, and each becoming a separate source of thunder, all the varieties of that awful sound are easily accounted for.

362. The *Speaking Trumpet* has been supposed by most writers on sound, to owe its peculiar properties to its multiplying sound by numerous reflexions. Hence is suggested the form of a parabolic conoid, or a tube, the section of which is a parabola, the place of the mouth being at the focus of a parabola. The vibrations emanating from the mouth would then be reflected into straight lines parallel with the axis of the trumpet, and would thus go forward in a collected body to a distant point. And, since such a form is also favorable for collecting distinct sounds into one point, the same figure is proposed as most suitable for the *Ear Trumpet*. But the sound of these instruments may be regarded as merely the longitudinal vibration of a body of air, to which momentum is given in the direction of the axis, not by reflexion from the sides, but by the direct impulse of the mouth. The ancients were acquainted with the speaking trumpet. Alexander the Great is said to have had a horn, by means of which he could give orders to his whole army at once.

363. When separate sounds are repeated with a certain degree of frequency, the ear loses the power of distinguishing the intervals, and they appear united in one continued sound. By this means also, sounds, harsh and dissonant in themselves,

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Why is the sound of thunder so much prolonged? To what does the *speaking trumpet* owe its power? What figure is considered best? To what does the *ear trumpet* owe its efficacy? What is the result when separate sounds are repeated with a certain degree of frequency?

form a soft and agreeable tone. Any sound whatever, repeated not less than thirty or forty times in a second, excites in the hearer the sensation of a musical note. Nothing is more unlike a musical sound than that of a quill drawn slowly across the teeth of a coarse comb; but when the quill is applied to the teeth of a wheel whirling at such a rate that 720 teeth pass under the quill in a second, a very soft, clear note is heard. In like manner the vibrations of a long harp-string, while it is very slack, are separately visible, and the pulses produced by it in the air are separately audible; but as it is gradually tightened, its vibrations quicken, and the eye soon sees, when it is moving, only a broad shadowy plane; the distinct sounds which the ear lately perceived, run together, owing to the shortness of the intervals, and are heard as one uniform continued tone, which constitutes the note or sound proper to the string.

Nature presents us with numerous examples of a musical sound produced by the rapid succession of an individual sound, not at all musical in itself. The hum of winged insects, produced by the frequent motion of their wings, the murmur of a forest, occasioned by the agitation of the leaves and boughs, and the sublime roar of the ocean, constituted of the separate sounds produced by innumerable waves, are familiar examples of the operation of this principle.

364. *Musical intervals*, or sounds differing from each other in pitch by a certain interval, are found by experience to be peculiarly agreeable to the human ear; a fact for which we can assign no reason, except that such is the constitution of the mind. Birds may sometimes exhibit a fine voice; but their singing is not musical, having nothing to do with musical intervals.

Musical sounds have certain *ratios* to one another, and are thus brought into the province of Mathematics, because the number of vibrations which produce one musical note, has a constant ratio to the number which produces another musical note. Thus, if we diminish the length of a musical string one half, we double the number of its vibrations in a given time, and it gives a sound eight notes higher in the scale than that given by the whole string. Therefore, these sounds are represented by the numbers 2 and 1, and are said to be in the ratio of 2 to 1. The upper note is said to be the *octave* of the lower;

Examples in the sound of a quill and comb, and in a harp string. Examples in nature. What does experience decide respecting musical intervals? *Why are musical sounds brought into the province of the mathematics? What is an octave?*

[illegible] *fundamental* note, or that [illegible] is considered as the commencement [illegible] the same series; so that all audible [illegible] series contained within [illegible]

[illegible] sounds constitutes *melody* [illegible] sounds at proper intervals, forms [illegible] constitutes *harmony*. Two [illegible] number of vibrations in a given [illegible] the same sound, are said to be in [illegible] and its octave is next [illegible] most perfect in nature; and when [illegible] the same time they almost entirely [illegible] frequent *coincidences* of [illegible] such coincidences are more [illegible] the vibrations are perfectly isochronous [illegible] at the end of every vibration [illegible] the shorter metal while performing just [illegible] they coincide at the end of [illegible] the longer string the shorter vibrating [illegible] the second, the longer [illegible] of the longer [illegible] eight of [illegible] the shorter [illegible] is [illegible]

[illegible] *chords* and discords [illegible] the major and minor thirds, [illegible] and are pleasing in [illegible] sevenths, the minor fifth and [illegible] of the fundamental [illegible] the harmonic [illegible] harmony and contains the constituent [illegible] natural melodies.

[illegible] are employed in musical composition [illegible] On the occasion [illegible] them, the following extract [illegible] will give the learner a general [illegible] new [illegible] sweet and useless things,

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[illegible] music. [illegible] the first and the [illegible] the [illegible]

to want qualification to keep off languor and satiety, when some bold musician had the courage and address to render it piquant and interesting, by means of discords, in order to stimulate attention; and thus by giving the ear a momentary uneasiness, and keeping it in suspense, its delight became the more exquisite, when the discordant difficulty was solved. Discord in musical composition, however, does not consist in the excess or defect of intervals, which, when false, produce jargon, not music; but in the warrantable and artful use of such combinations as, though too disagreeable for the ear to dwell upon, or to furnish a musical period, yet so necessary are they to modern counterpoint, and modern ears, that harmony without their relief, would satiate, and lose many of its beautiful effects."

367. The theory of *Musical Instruments* will be readily understood from the principles already explained. It will be seen that they all owe their power of producing musical sounds to their susceptibility of vibrations; that the force or loudness of the sounds they afford depends on the *length* of the vibrations, and the graveness or acuteness of the sound, in other words, the pitch, on their *slowness* or *frequency;* and that their chords depend, in general, upon *frequency of coincidence in the vibrations* that afford the several sounds of the concord. The nature of stringed instruments may be learned from the *violin.* Here the strings are of the same length, but differ in weight and tension; those designed to afford the lower notes being heavier and less strained, and those for the higher notes being lighter and more tense. The lengths, moreover, are altered by applying the fingers. The several strings are usually so adjusted to each other, that is, so *tuned*, that any two contiguous strings make a *fifth.* Hence the fourth, or highest stop on one string, brings it into unison with the string above; and the third stop on any string forms an octave with the open string next below. On account of this power of altering the effective lengths of the strings at pleasure, of developing the harmonic sounds by a skilful application of the fingers, and of varying constantly the degrees of fullness or force in each sound, by a dexterous use of the bow, the violin becomes, in the hands of an accomplished performer, an instrument of great power and compass, while it is capable of greater variety than any other musical instrument.

To what do *musical instruments* owe their power? On what does their *force* or *loudness* depend? On what the *pitch?* On what the chords? Explain *these principles* from the violin. How is it tuned?

The *flute* affords an example of wind instruments. Here the vibrating body is a column of air, to which different lengths are given by means of the stops which are opened and closed by the fingers. The rapidity of the vibrations, and consequently the pitch, is also changed a whole octave by the management of the breath.

368. In mixed wind instruments, the vibrations or alternations of solid bodies are made to co-operate with the vibrations of a given portion of air. Thus, in the trumpet, and in horns of various kinds, the force of inflation, and perhaps the degree of tension of the lips, determines the number of parts into which the tube is divided, and the harmonic which is produced. The hautboy and clarionette have mouth-pieces of different forms, made of reeds or canes; and the reed-pipes of an organ, of various constructions, are furnished with an elastic plate of metal, which vibrates in unison with the column of air which they contain. An organ generally consists of a number of different series of pipes, so arranged, that, by means of registers, the air proceeding from the bellows may be admitted to supply each series, or excluded from it at pleasure; and a valve is opened when the proper key is touched, which causes all the pipes belonging to the note, in those series of which the registers are open, to sound at once.

What is the vibrating body in the flute? Explain how its sounds are produced and varied. Explain the theory of mixed wind instruments, as the trumpet, the hautboy, and the organ.

PART IV.—ELECTRICITY.

CHAPTER I.

OF THE GENERAL PRINCIPLES OF THE SCIENCE.

369. The term ELECTRICITY is used to denote both the unknown *cause* of electrical phenomena, and the *science* which treats of electrical phenomena and their causes.

The most general effect by which the presence of electricity is manifested is *attraction*. Thus, when a glass tube is rubbed with a dry silk or woolen cloth, it acquires the property of attracting light bodies, as cotton, feathers, &c. When, by any process, a body is made to give signs of electricity, it is said to be *excited*. When a body receives the electric fluid from an excited body, it is said to be *electrified*. Since there is found to be a great difference in bodies in regard to the power of transmitting electricity, all bodies are divided into two classes, CONDUCTORS and NON-CONDUCTORS. *Conductors* are bodies through which the electric fluid passes readily; *non-conductors* are bodies through which the electric fluid either does not pass at all, or but very slowly. The latter bodies are also denominated *electrics*, because it is by the friction of bodies of this class that electricity is usually excited. An electrified body is said to be *insulated*, when its connexion with other bodies is formed by means of non-conductors, so that its electricity is prevented from escaping. Instruments employed to detect the presence of electricity are denominated *electroscopes;* such as are employed to estimate its comparative quantity, are called *electrometers*. This distinction, however, is neglected by some writers, and, to avoid the unnecessary multiplication of terms, it will be neglected in the present treatise, instruments of either kind being called *electrometers*.

370. The *Pendulum Electrometer* is formed by suspending some light conducting body by some non-conducting sub-

Electricity.—In what two senses is the term used? By what effect is the presence of electricity manifested? When is a body said to be excited?—when electrified? Define conductors and non-conductors. Why are the latter called electrics? When is a body said to be insulated? Define electroscopes and electrometers. How is the pendulum electrometer *formed?*

stance. Thus, *a small ball of the pith of elder, hung by a silk thread*, constitutes a very convenient instrument for detecting the presence and examining the kind of electricity. Figure 84, represents a pendulum electrometer, consisting of a glass rod fixed in a stand, and bent at the top so as to form a hook. From this hook hangs a thread of raw silk, to the bottom of which is attached a small pith ball, made smooth and round, and weighing only a small part of a grain. The attenuated thread of silk, unwound from the ball of the silk worm, forms a very delicate insulator; but for ordinary purposes, a common thread of silk may be untwisted, and a single filament taken for the suspending thread. For the purposes of the learner, it may even be sufficient to suspend a ball of cork, or a lock of cotton, or a feather by a thread of silk. The *Gold Leaf Electrometer*, represented in Fig. 85, consists of two strips of gold leaf suspended from the metallic cover of a small glass cylinder. By this arrangement, the pieces of gold leaf are insulated; they are protected from agitation by the air, and Electricity is easily conveyed to them by bringing an electrified body into contact with the cover. The approach of an electrified body causes the leaves to separate, or when previously separated, to collapse according to principles to be explained presently.

Fig. 84.

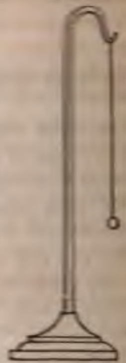

Fig. 85.

By the aid of the foregoing instruments, or even by means of the pendulum electrometer alone, we may ascertain the following LEADING FACTS, which are so many fundamental truths, in the science of Electricity.

371. PROP. I. *Electricity is produced by the Friction of all bodies.*

Although friction is the most common, and by far the most extensive means of exciting bodies, yet it is not the only means. Electricity is manifested during the *changes of state* in bodies, such as liquefaction and congelation, evaporation

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Describe the gold leaf electrometer. How is electricity produced? By what means beside friction?

and condensation. Some bodies even are excited by mere *pressure*; others by the *contact* or *separation of different surfaces*. Most *chemical combinations and decompositions* are also attended by the evolution of Electricity, which manifests its presence to delicate electrometers.

If we rub a piece of amber, sealing wax, or any other resinous substance on dry woolen cloth, or fur, or silk, and bring it towards an electrometer, it will give signs of electricity. A glass tube may be excited in a similar manner. Moreover, if we bring the excited tube near the face, it imparts a sensation resembling that produced by a cobweb. If the tube is strongly excited, it will afford a spark to the knuckle, accompanied by a snapping noise. A sheet of white paper, first dried by the fire, and then laid on a table and rubbed with India rubber, will become so highly excited as to adhere to the wall of the room, or any other surface to which it is applied. Indeed, friction is so constantly attended by Electricity, that in favorable weather the fluid is abundantly indicated on brushing our clothes, which thus are made to attract the light downy particles that are floating in the air.

372. Our proposition asserts that Electricity is produced by the friction of *all* bodies, whereas if we hold in the hand a metallic substance, a plate of brass or iron, for example, and subject it to friction, we shall not discover the least sign of electrical excitement. In such cases, however, the Electricity is prevented from accumulating in consequence of the substance being a *good conductor*, and thus conveying the fluid to the hand, which is another good conductor, by which means it is lost as fast as it is excited. But if we insulate a metallic body, or any other conducting substance, then, on being rubbed, it gives signs of Electricity, like electrics.

373. PROP. II. *The Electricity which is excited from* GLASS, *and a numerous class of bodies, exhibits different properties from that which is excited from* AMBER, *or sealing wax, and a class of bodies equally numerous with the other.*

The kind of fluid excited from glass and analogous bodies is called *vitreous*, and that from amber and analogous bodies, *resi-*

Recite the experiments with a piece of amber, with a glass tube, and with a sheet of white paper. Are *all* bodies capable of being electrified by friction? State the proposition comparing the respective properties of glass and amber. Explain the terms vitreous and resinous, positive and negative.

nous Electricity. The term *positive* is also used instead of vitreous, and *negative* instead of resinous.

In order to understand the applications of the preceding terms *vitreous* and *resinous*, *positive* and *negative*, it is necessary to know something of the two hypotheses upon which these terms are respectively founded. The first hypothesis is that proposed by *Du Fay*. It ascribes all electrical phenomena to the agency of *two* fluids specifically different from each other, and pervading all bodies. In unelectrified bodies, these two fluids exist in combination, and exactly neutralize each other. By the separation of the two fluids it is that bodies are electrified, and it is by the re-union of the two fluids, that the Electricity is discharged, or bodies cease to be excited. The second hypothesis was proposed by Dr. Franklin. It ascribes all electrical phenomena to the agency of *one* fluid, which, as in the other case is supposed to pervade all bodies, being naturally in a state of equilibrium. It is only when this equilibrium is destroyed that bodies become electrified, and it is by the restoration of the equilibrium that the Electricity is discharged, or bodies cease to be excited. But a body is electrified when it has either more or less of the fluid than its natural share; in the former case it is *positively*, in the latter case *negatively*, electrified; positive Electricity, therefore, implies a redundancy, and negative Electricity, a deficiency of the fluid.

374. PROP. III. *Bodies electrified in different ways attract, and in the same way repel each other.*

Thus, if an insulated pith ball, (Art. 370.) or a lock of cotton, be electrified by touching it with an excited glass tube, it will immediately recede from the tube, and from all other bodies which afford the vitreous Electricity, while it will be attracted by excited sealing wax, and by all other bodies which afford the resinous Electricity. If a lock of fine, long hair, be held at one end, and brushed with a dry brush, the separate hairs will become electrified, and will repel each other. In like manner, two insulated pith balls, or any other light bodies, will repel each other when they are electrified the same way, and attract each other when they are electrified different ways.

Explain the hypothesis of Du Fay, and that of Franklin. According to Du Fay's hypothesis, what takes place when electricity is excited, and what when it is discharged? How do bodies affect each other when electrified the same way, and how when electrified different ways? State the experiments with a lock of cotton or of hair.

Hence it is easy to determine, *whether the Electricity afforded by a given body is vitreous or resinous;* for, having electrified the electrometer by excited glass, then all those bodies which, when excited, *attract* the ball, afford the resinous, while all those which *repel* the ball, afford the vitreous Electricity.

375. PROP. IV. *The two kinds of electricity are produced simultaneously; the one kind in the body rubbed, the other in the rubber.*

For example, if we rub a glass tube with a silk or woolen cloth, the glass becomes positive, and the cloth negative. The foregoing law holds true universally; but the kind of Electricity which each substance acquires, depends upon the substance against which it is rubbed. If we rub dry woolen cloth against *smooth* glass, it acquires the resinous, and the glass, the vitreous Electricity; but if we rub the same cloth against *rough* glass, it becomes positively, while the glass becomes negatively, electrified. The following table contains a number of electric substances, arranged in such a way that when they are rubbed against each other, any substance in the list above another, becomes positively, and any substance below it, negatively electrified.

1. Fur of a Cat,	6. Paper,
2. Smooth Glass,	7. Silk,
3. Woolen Cloth,	8. Lac,
4. Feathers,	9. Rough Glass,
5. Wool,	10. Sulphur.

The fur of a cat, when rubbed against any of the bodies in the table, always affords the vitreous, and the sulphur always the resinous electricity. Feathers become negative when rubbed against the fur of a cat, smooth glass, or woolen cloth; but positive when rubbed against wool, paper, silk, lac, rough glass, or sulphur.

376. PROP. V. *Electricity passes through some bodies with the greatest facility; through others with the greatest apparent difficulty, or scarcely at all; and others have a conducting power intermediate between the two.*

How can we determine the kind of electricity produced in a given case? How do the electricities of the rubber and the body rubbed compare with each other? What kind of electricity does the fur of a cat give? What kind does sulphur give? When do feathers give positive, and when negative? Recite proposition V, respecting the conducting powers of different bodies.

Metals and charcoal, water and all liquids, (oils excepted,) are good conductors. *Melted* wax and tallow are good conductors; but these bodies while solid conduct very badly. Glass, resins, gums, sealing wax, silk, sulphur, precious stones, oxides, air, and all gases, are non-conductors, or at least very bad conductors. Atmospheric air is a non-conductor of the highest class, when perfectly dry; but it becomes a conductor, either when moist or when rarefied. The electric fluid easily pervades the vacuum of an air pump, or of the Torricellian tube; but these are imperfect vacuums; it is said that Electricity cannot pass through a perfect vacuum. The conducting powers of most bodies are influenced by changes of temperature, and also by changes of form. Water, in its natural state, is a good conductor; but its conducting power is increased by heat and diminished by cold.

The same body frequently exhibits great changes in conducting power by changes of state, or chemical constitution. Thus, green wood is a conductor, dry baked wood a non-conductor; charcoal a conductor, ashes a non-conductor. It is particularly important to remember that Metals, Water, and all moist substances, Animal substances, as the human body, and the Earth itself, are *conductors;* while the Air, when dry, and all Resinous and Vitreous substances, are *non-conductors.* These bodies are those which are chiefly concerned in making experiments with electrical apparatus.

377. Prop. VI. *Insulation is effected in various degrees of perfection, according to the state of the atmosphere, and the nature of the substances employed as insulators.*

If the air were a conductor, it is not easy to see how the electric fluid could be confined so as to be accumulated. It is, moreover, only when the air is *dry* that it is capable of insulating well; hence, in damp, foggy, and rainy weather, electrical apparatus will not work well, unless the air is dried artificially by operating in a close room highly heated by a stove. Lac, drawn into fine threads, is the most perfect insulator. Compared with silk thread, such a filament is ten times more effectual in preventing the loss of the fluid. Fine silk thread, however, when perfectly dry, is among the best insulators; and

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Enumerate the best conductors and the best non-conductors. Can electricity pass through a vacuum? What changes in conducting power result from bodies being moist or dry? Mention the best methods of insulating.

where great delicacy is required, a single filament of silk, as it comes from the ball of the silk worm, is employed. Its conducting power is somewhat influenced by its color, black being the worst, and a gold yellow the best color for insulating. Glass is much used as an insulator, especially when great strength is required, as in supports to various kinds of electrical apparatus. Glass, however, is liable to acquire moisture on its surface, in consequence of which its properties as an insulator are materially impaired. This inconvenience is obviated by giving it a thick coat of varnish. Fine hair is a good and convenient substance in some cases of insulation.

In some cases, conducting or uninsulating threads are required. Then fine silver wires, or linen threads first steeped in a solution of salt, and dried, are used.

378. The *sphere of communication* is the space within which a spark may pass from an electrified body, in any direction from it. It is sometimes called the striking distance. The *sphere of influence* is the space within which the power of attraction of an electrified body extends in every way, beyond the sphere of communication. A glass tube strongly excited will exert an influence upon the gold leaf electrometer at the distance of ten or even twenty feet, although a spark could not pass from the tube to the cap of the electrometer at a greater distance than a few inches.

379. The electricity which a body manifests by being brought near to an excited body, without receiving a spark from it, is said to be acquired by *Induction*.

When an insulated conductor, unelectrified, is brought into the neighborhood of an insulated charged conductor, its Electricity undergoes a new arrangement. The end of it next to the excited conductor, assumes a state of electricity opposite to that of the excited conductor; while the farther extremity assumes the same kind of electricity. Suppose the excited conductor is electrified positively. The end of the insulated conductor next to it, becomes negative, and the remoter end, positive; and intermediate between these two points, there occurs a place where neither positive nor negative electricity can be perceived. This place is called the *neutral point.*

Define the sphere of communication—also, the sphere of influence. Define induction. Explain the difference of arrangement in the electricity of an insulated conductor, when brought near a charged conductor.

The reason why unelectrified bodies are attracted by excited electrics, is, that they are put into the opposite state by induction, and then attracted upon the general principle laid down in Prop. III. When they come into the sphere of communication of the excited body, they immediately acquire the same kind of electricity, and are repelled. If they come into contact with uninsulated bodies, they lose the electricity they have acquired, are again put into the opposite state by induction, again attracted and again repelled. This process will go on until the electricity of the insulated conductor is all conveyed away.

The foregoing general principles may be verified with very simple apparatus, such as pith balls, a glass tube, and a stick of sealing wax. But the same facts may be exhibited in a much more striking and impressive manner by the electrical machine and its appendages, and our attention will therefore be now turned to the consideration of the subject of electrical apparatus.

CHAPTER II.

OF ELECTRICAL APPARATUS.

380. The object of the electrical machine is to *accumulate* electricity. It is made of several different forms, but two of these forms are predominant, which it will be sufficient for our present purpose to describe; of these, one is called the Cylinder, the other, the Plate machine. The CYLINDER MACHINE is represented in Fig. 86. The principal parts belonging to it, are the cylinder, the frame, the rubber, and the prime conductor. The *cylinder* (A) is of glass, from eight to twelve inches in diameter, and from twelve to twenty-four inches long. It should be perfectly cylindrical, otherwise it will not press the cushion or rubber evenly when turned. It must be as smooth as possible, for rough glass becomes a partial conductor. The cylinder should be so mounted on the frame as to revolve without waddling, for such a motion would prevent its being in uniform contact with the rubber. The *Frame* (BB) is made of wood, which must be close grained, well seasoned,

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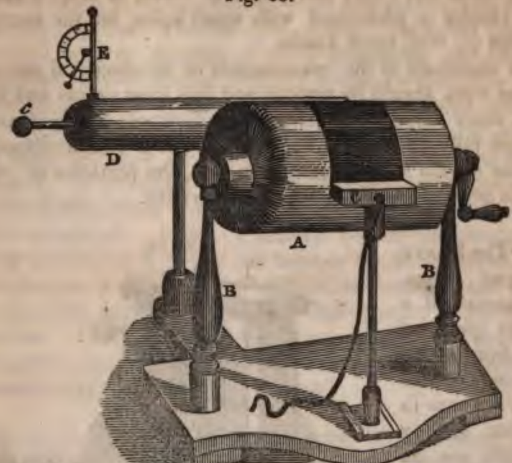
Why are unelectrified bodies attracted by such as are electrified? *Electrical Apparatus.*—What is its object? What are the two usual forms? Describe the *Cylinder Machine*—the cylinder, of what made—*its size*—figure—smoothness, &c. How mounted?

and baked in an oven, and finally coated with varnish; the object of all this preparation being to diminish its conducting powers, and thus prevent its wasting the electricity of the cyl-

Fig. 86.



inder. The *Rubber* (C) consists of a leathern cushion, stuffed with hair like the padding of a saddle. This is covered with a black silk cloth, having a flap which extends from the cushion over the top of the cylinder, to the distance of an inch from the points connected with the prime conductor, to be mentioned presently. The rubber is coated with an amalgam* made of mercury, zinc, and tin, which preparation has been found, by experience, to produce a high degree of electrical excitement, when subjected to the friction of glass. The rubber is insulated by placing it on a solid glass pillar, and it is made

The *frame*—of what made—how coated? The *rubber*—of what made—how covered—how coated—how insulated? What is the composition of the *amalgam?*

* The amalgam recommended by Singer, one of the ablest practical electricians, is composed of zinc two ounces, of tin one ounce, and of mercury six ounces. The zinc and tin may be melted together in a ladle, or crucible, and poured into a mortar, previously heated to prevent the sudden congelation of the melted metals. As soon as they are introduced, they must be rapidly stirred with the pestle, during which process the mercury may be added, and the stirring continued until the amalgam is cold, when it will be in the form of paste, or fine powder. A little lard is added to give the amalgam the proper consistence; but if, when applied, it be warmed a little, but a *small proportion of lard* need be used. In hot weather, less quicksilver is to be *employed.*

to fit closely to the cylinder by means of a spring, worked by a screw.

The *Prime Conductor* (D) is usually a hollow brass cylinder with hemispherical ends. It is mounted on a solid glass pillar, with a broad and heavy foot, made of wood, to keep it steady. The cylinder is perforated with small holes, for the reception of wires (*e*) with brass knobs.

It is important to the construction of an electrical machine, that the work should be smooth and free from points and sharp edges, since these have a tendency to dissipate the fluid, as will be more fully understood hereafter. For a similar reason the machine should be kept free from dust, the particles of which act like points, and dissipate the electricity.

Fig. 87.

381. The PLATE MACHINE (Fig. 87.) consists of a circular plate of glass, from eighteen to twenty-four inches or more in diameter, turning vertically on an axis that passes through its center. The frame is composed of materials similar to those which compose the frame of the cylindrical machine. This machine is furnished with two pairs of rubbers, attached to the top and bottom of the plate. The prime conductor consists of a brass cylinder, proceeding from the center in a line with the axis, and having two branches which serve to increase its surface, and at the same time to connect it with the opposite sides of the plate, so as to receive the electricity as it is evolved from each cushion.

The prime conductor—of what made—how mounted—why perforated with holes? The *Plate Machine*—of what does it consist? How many rubbers are used? How is the prime conductor constructed?

It is not agreed which of these two machines affords the greatest quantity of Electricity from the same surface; but the cylinder is less expensive than the plate, and less liable to break, and is more convenient for common use.

382. The principles of the electrical machine, will be readily comprehended from what has gone before. It differs from the glass tube, only in affording a more convenient and effectual mode of producing friction. By the friction of the glass cylinder or plate against the rubber, electricity is evolved, which is immediately transferred to the prime conductor, and may be taken from the latter by the knuckle, or any other conducting substance. If the glass and rubber both remain insulated, the quantity of Electricity which they are capable of affording, will soon be exhausted. Hence, a chain or wire is hung to the rubber and suffered to fall upon the table or the floor, which, communicating as it does with the walls of the building, and finally with the earth, supplies an inexhaustible quantity of the fluid to the rubber. In cases where very great quantities of electricity are required, a metalic communication may be formed immediately between the rubber and the ground.*

383. In order to indicate the degree of excitement in the prime conductor, the *Quadrant Electrometer* is attached to it, as represented at E in Fig. 86. This electrometer is formed of a semicircle, usually of ivory, divided into degrees and minutes, from 0 to 180,† the graduation begining at the bottom of the arc. The index consists of a straw, moving on the center of the disk,

What advantage has the cylinder over the plate machine? How does the electrical machine differ from the glass tube? How does it afford electricity? Why must the rubber be connected, by a conductor, with the ground? Describe the mode of constructing a cheap electrical aparatus? What may be used for the cylinder? how mounted? what may be used for the prime conductor, for insulators &c.? What is the composition of electrical cement? Describe the quadrant electrometer?

* As electrical machines are expensive, and not always easily procured by the private learner, it may be useful to suggest a mode of fitting up a cheap apparatus. A large tincture bottle may be procured of the apothecary, for the cylinder. A cover of wood may be cemented to each end, to the center of which, next to the bottom, is screwed a projecting knob for one end of the axis, while the part of the axis to which the handle is attached, is screwed into the center of the cover of wood next to the nozzle. Thus prepared, it may be mounted on such a frame of hard dry wood as every joiner or cabinet maker can construct. A tinner can make the prime conductor, and several other appendages to be described hereafter. Junk bottles or long vials serve well as insulators. Ingenious students of electricity, frequently amuse themselves with making machines of this description, some of which have answered nearly every purpose of the most expensive kinds of apparatus.

A *cement*, for electrical purposes, may be made by melting together five ounces of resin, one ounce of beeswax, one ounce of Spanish brown, and a tea spoonful of plaster of Paris, or brick dust.

† *Sometimes the division is carried* only to ninety degrees, which is all that is necessary.

and carrying at the other extremity, a small pith ball. The perpendicular support is a pillar of brass, or some conducting substance. When this instrument is in a perpendicular position and not electrified, the index hangs by the side of the pillar, perpendicularly to the horizon; but when the prime conductor is electrified, it imparts the same kind of electricity to the index, repels it, and causes it to rise on the scale towards an angle of 90°, or to a position at right angles with the pillar.

384. When an electrical machine is skilfully fitted up, and works well, on turning it, circles of light surround the cylinder or plate, and brushes or pencils of light emanate copiously from the cushion and other parts of the machine. The circles of light consist of electric sparks, which discharge themselves between the excited surface and the rubber, their passage being so rapid as to appear like a continued line, like that of a small stick ignited at the end and whirled in the air. The brushes of light arise from the facility with which the fluid escapes from points or thin edges.

The experiments which were previously performed on electrical attractions and repulsions, (Arts. 369—376.) may now be repeated in a much more striking manner, and various other experiments added, which can be shown only when electricity is accumulated.

385. We proceed to enumerate a few of the effects of electricity as they are exhibited by the electrical machine, confining ourselves, for the present, to those experiments which relate to attraction and repulsion, and the passage of the spark, reserving such as relate to light and heat to future sections. The following effects may be observed with a machine of moderate powers, the rationale of which the learner will readily supply from the proposition given in Art. 378.

(1.) When the machine is turned, a downy feather, or a lock of cotton held in the hand by a conducting thread,* will be strongly attracted towards the excited surface.

(2.) A skein of thread, or lock of fine hair, looped and suspended by the loop from the prime conductor, will exhibit strong repulsions between the threads or hairs.

What appearances does the machine, when well fitted up, exhibit? *Experiments.*—Describe the experiment with a feather or lock of cotton—with a skein of thread.

* *The conducting* power of linen or cotton threads is improved by moistening them *with the breath.*

(3.) The quadrant electrometer, being attached to the prime conductor, the conducting powers of different substances may be readily tried. Thus, an iron rod held in the hand, and applied to the prime conductor, will cause the index of the electrometer to fall instantly; and the same effect will follow the application of any metallic rod. A wooden rod of the same dimensions, will cause the index to descend more slowly; and a glass rod will hardly move it at all. These experiments show that iron is a perfect, and wood an imperfect conductor, and glass a non-conductor. In the same manner the conducting powers of a stick of sealing wax, a roll of silk, or cloth, and of various other bodies, may be illustrated.

(4.) If a pith ball, or feather, or any other light body held by a silk thread, be presented to the prime conductor, it will first be attracted and then repelled, and it cannot again be brought into contact with the electrified conductor until its electricity is discharged by communicating with the finger or some unelectrified conductor.

(5.) By placing light bodies between an electrified conductor and an uninsulated body, they may be made to move with great rapidity backwards and forwards, from one surface to the other, being alternately attracted and repelled by the electrified surface. By this means are performed electrical dances, the ringing of bells, and a variety of interesting and amusing experiments.

(6.) If the rubber be *insulated* while the machine is turned, the rubber and the glass cylinder, or plate, will be found to be in different electrical states; an insulated body attracted by the one will be repelled by the other.

Bodies are electrified positively by connecting them with the glass, by means of the prime conductor, and negatively by connecting them with the rubber, the latter being insulated, and the prime conductor uninsulated.

(7.) An electrified body frequently exhibits a tendency to separate into minute parts, these parts being endued with the power of mutual repulsion. Thus a lock of cotton, when electrified, is separated into its minutest fibres. Melted sealing wax, when attached by a wire to the prime conductor, is divided into filaments so small as to resemble red wool. Water dropping from a capillary syphon tube, on being electrified, is made to run out in a great number of exceedingly fine streams. Water spout-

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Effects of electrrcity on the conducting powers of bodies—on attraction and repulsion—on the different states of the machine and rubber. How are bodies electrified positively—how negatively? What bodies separate *into fibres when electrified?*

[illegible] fountain (Art. 291.) is divided into a number of [illegible] the appearance of a brush.

[illegible] of electrified air, in consequence of the mutual [illegible] between its particles, expands, and when at liberty to [illegible] becomes rarefied. Thus, a current of air may be set in [illegible] from an electrified point, or small ball, or be made to [illegible] the neck of a bottle.

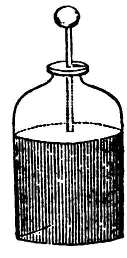
[illegible] are some of the leading experiments which may be per[illegible] with the common electrical machines, in addition to those [illegible] are connected with light and heat, to be more particularly [illegible] hereafter.

[illegible] *The force of electral attraction or repulsion, at different* [illegible] *from an electrified body, varies inversely as the square* [illegible] *distance.*

Hence electrified bodies exhibit strong attractions and repulsions only when very near to each other, and the force decreases rapidly with the distance, being diminished four times by doubling the distance, and nine times by trebling it. It is worthy of remark, that the foregoing law is the same as that of gravitation.

Electricity resides only at or near the *surfaces* of bodies. A hollow metallic globe, for example, takes the same charge as a solid globe of the same dimensions. Bodies of different figures, however, have the electricity distributed over their surfaces in different manners. Thus, in a conductor of an elongated figure, the electricity is accumulated towards the two ends, and more or less withdrawn from the central parts.

Fig. 88.



The Leyden Jar.

387. This instrument, which is a very important article of electrical apparatus, consists of a glass jar, coated on both sides with tin foil, except a space on the upper end, within two or three inches of the top, which is either left bare, or is covered with a coating of varnish, or a thin layer of sealing wax. To the mouth of the jar is fitted a cover of hard baked wood, through the

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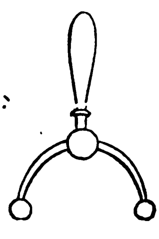
On what principle is a current of air set in motion from an electrified point? How is the force of electrical attraction and repulsion at different distances? On what part of bodies does electricity reside? Is the distribution affected by difference in figure in bodies? How is the electricity accumulated on conductors of an elongated figure? Leyden Jar—of what does it consist? Describe it—how charged and discharged.

center of which passes a perpendicular wire, terminating above in a knob, and below in a fine chain, that rests upon the bottom of the jar. On presenting the knob of the jar near to the prime conductor of an electrical machine, while the latter is in operation, a series of sparks passes between the conductor and the Jar, which will gradually grow more and more feeble, until they will cease altogether. The Jar is then said to be *charged.* If we now take the *Discharging Rod,* (which is a crooked wire, armed at each end with knobs, and insulated by a glass handle, as in Fig. 89,) and apply one of the knobs to the outer coating of the Jar, and bring the other to the knob of the Jar, a flash of intense brightness, accompanied by a loud report, immediately ensues. On applying the discharging rod a second time, a feeble spark passes, being the *residuary charge,* after which all signs of electricity disappear, and the Jar is said to be *discharged.*

Fig. 89.



388. If, instead of the discharging rod, we apply one hand to the outside of the charged Jar, and bring a knuckle of the other hand to the knob of the Jar, a sudden and surprising *shock* is felt, convulsing the arms, and, when sufficiently powerful, passing through the breast.

389. The Leyden Jar derives its name from the place of its discovery. In the year 1746, while some philosophers of Leyden were performing electrical experiments, one of them happened to hold in one hand a tumbler partly filled with water, to a wire connected with the prime conductor of an electrical machine. When the water was supposed to be sufficiently electrified, he attempted, with the other hand, to detach the wire from the machine; but as soon as he touched it, he received the electric shock. It was by imitating this arrangement, that the Leyden Jar was constructed; for here was a glass cylinder, having good conductors on both sides, viz. the hand on the outside, and the water on the inside, which were prevented from communicating with each other by the non-conducting powers of the glass. A metallic coating, as tin foil or sheet lead, was substituted for the

Describe the discharging rod. What sensation is experienced on receiving the charge on the knuckle? Give the history of the Leyden Jar. What resemblance have the several parts of the Jar to the accidental combination which first led to its discovery?

two conductors, and a jar for the glass cylinder, and thus the electrical jar was constructed.

390. Those who first received the electric shock from the Leyden Jar, gave the most extravagant accounts of its effects. M. Muschenbroeck, a philosopher of Leyden, of much eminence, said that "he felt himself struck in his arms, shoulders, and breast, so that he lost his breath; and it was two days before he recovered from the effects of the blow and the terror; adding, that he would not take a second shock for the kingdom of France." M. Winkler, of Leipsic, asserted that "the first time he tried the Leyden experiment, he found great convulsions by it in his body; and that it put his blood into great agitation, so that he was afraid of an ardent fever, and was obliged to use refrigerating medicines. He also felt a heaviness in his head, as if a stone lay upon it, and twice it gave him a bleeding at the nose."

391. In an age less enlightened than the present, and less familiar with the wonders of philosophy and chemistry, the striking and truly surprising effects of Electricity, as exhibited by the Leyden Jar, would naturally excite great admiration and astonishment. Accordingly, showmen travelled with this apparatus through the principal cities of Europe, and probably no object of philosophical curiosity ever drew together greater crowds of spectators. It was this astonishing experiment, (says Dr. Priestley,) that gave eclat to Electricity. From this time, it became the subject of general conversation. Every body was eager to see, and, notwithstanding the terrible account that was reported of it, to *feel* the experiment; and in the same year in which it was discovered, numbers of persons, in almost every country in Europe, got a livelihood by going about and showing it. All the electricians of Europe, also, were immediately employed in repeating this great experiment, and in attending to the circumstances of it. With similar assiduity and unequalled success, Dr. Franklin betook himself to experiments on the Leyden Jar. He effectually investigated all its properties, by very diversified and ingenious experiments, and gave the first rational explanation of the cause of its phenomena. The following experiments may be easily repeated.

392. (1.) *The Jar is charged by bringing the knob near the prime conductor, while the machine is in operation.* One mode of charging the Jar has been already mentioned in Art. 387.

State the accounts at first given of the shock. State facts showing the celebrity of the Leyden Jar. Experiments.—How is the jar charged?

It may, however, either be held in the hand, or placed on the table, or on any conducting support: the only circumstance to be attended to is, that the outside shall be uninsulated. A Jar, while charging, will sometimes discharge itself spontaneously. This effect will be more likely to happen, if the uncoated interval is very clean and dry, and may be prevented altogether, by previously breathing on the uncoated part.

(2.) *The opposite sides of a charged Jar, are in different electrical states, the one positive and the other negative.* Thus, if a pith ball, suspended by a silk thread, be applied to the knob, it will first be attracted to it, and then repelled; but it will now be attracted by the outside coating, until it becomes electrified in the same way, and then repelled, and so on.

(3.) *In order to receive the charge, the outside of the Jar must be uninsulated.* If we attach a string to the knob of the Jar, and suspend it, in the air, to the prime conductor, and put the machine in operation, no charge will be communicated to the Jar. The same result will follow, if the Jar stands on an insulating stand,* or is insulated in any other method. An insulated Jar, however, may be charged by connecting its knob with the positive conductor, and its outer coating with the rubber.

(4.) *A second Jar may be charged, by communication with the outside of the first, while the latter is receiving its charge.* The charge communicated to the second Jar, is of the same kind as that of the first, and nearly of the same degree of intensity, provided the capacity of the two Jars be the same. Moreover, if a third, a fourth, or any number of Jars, of the same size, be connected in a similar manner, with each other; namely, having the knob of each in communication with the outside coating of the next preceding,—then all the Jars will be charged with the same kind of electricity, but the degree of intensity will decline a little in the successive Jars. If the charge be derived, through the prime conductor, from the cylinder or plate, as is usually the case, it will be the positive or vitreous electricity.

(5.) *A Jar may be charged negatively, by receiving the electricity of the rubber,*—the rubber being insulated, and the prime

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When is the jar apt to discharge itself spontaneously? In what states are the opposite sides of a jar? Will a jar receive a charge when insulated? How to charge a second jar from the first? If a series of jars be charged from the first, how is the strength of the charge in each? How to charge a jar negatively?

* An insulating stand, is any flat support, insulated by a pillar of glass. The pillar is usually a solid cylinder of glass, from six to twelve inches long, varnished so as to protect it from moisture. A junk bottle, surmounted by a circular piece of wood, dry and varnished, makes a very good insulating support.

conductor uninsulated. For this purpose, the chain usually attached to the rubber may be transferred to the prime conductor.

(6.) *When two Jars are charged, the one positively and the other negatively, on forming a communication between the insides of both, by connecting the two knobs, no discharge will take place, unless the outsides be in conducting communication.* Thus, if two Jars be charged, the one from the prime conductor and the other from the rubber,* and placed at the distance of a few inches from each other, on insulated supports, on connecting the two knobs by the discharging rod, no discharge will follow; but, let a wire be laid across the supports, touching the outside of each Jar: then, on applying the discharging rod to the two knobs, an explosion will immediately ensue.

By means of two Jars differently charged, and placed as above, with their outsides in conducting communication, the experiment may be exhibited, which is called the *Electrical Spider*. It consists of a small piece of cork, so fashioned as to represent the body of a spider, and blackened with ink, having a number of black linen threads drawn through it to represent the legs. This is suspended by a silk thread, half way between the knobs of the two Jars, and vibrates for a long time from one knob to the other, until both Jars are discharged. The rationale will be obvious on a little reflection.

(7.) *The charge of any Jar may be divided into definite parts;* that is, the half, the fourth, or any aliquot part of the charge may be taken. This may be done by connecting the inner and the outer coating of the charged Jar, with the inner and outer coating of an unelectrified jar, of the same size and thickness. The respective charges will be measured by the quadrant electrometer, (Fig. 86.)

(8.) *The electricity is accumulated on the surface of the glass, and the coatings serve merely as conductors of the charge.* This is proved by the fact, that when the coatings are movable, so that they can be taken off from the jar after it is charged, neither of them exhibits the least sign of electricity; while if another pair of coatings is substituted, which have not been electrified, on forming the communication between the inside and outside, the usual discharge takes place, showing that the whole of the charge was retained on the glass surfaces of the jar.

What is necessary in order that two jars, charged opposite ways, may be discharged? Describe the electrical spider. How may the charge of a jar be divided? On what part of a jar is the electric fluid accumulated?

*And both may be thus charged at the same time, by connecting one with the insulated rubber, and the other with the insulated prime conductor, the jars themselves being uninsulated.

(9.) *The charge of a Leyden Jar may be retained for a long time.* If the surfaces are well separated from each other, the charge remains for many days or even weeks. The charge is usually dissipated by the motion of particles of dust, or other conducting substances in the atmosphere, from one of the coatings to the other, or by the uncoated interval becoming moist, and losing its insulating power; consequently a jar will retain its charge longer in dry than in damp weather. Covering the uncoated part of the jar with melted sealing wax or varnish, prevents the deposition of moisture upon it, and consequently tends also materially to prevent the dissipation of its charge.

393. For the purpose of making the theory of the Leyden Jar familiar, we may now recur to the experiments mentioned in Art. 392, and attempt the explanation of them.

In the structure of the Jar, we recognise the operation of the principle of *induction.* Here, an unelectrified body (the outer surface) is brought very near to an electrified body, (the inner surface, without the possibility of communicating with each other, on account of the non-conducting properties of the glass. The nearer the two surfaces can be brought to each other, the more powerful is the effect of induction, that effect being inversely as the square of the distance. Accordingly, the thinner the jar, the more powerful is the charge it will receive; but the danger of breaking prevents our employing such as are very thin.

To trace the process of charging a jar a little more minutely, let us suppose the jar connected with the prime conductor of an electrical machine, from which a spark is communicated to the inner coating. This, according to the principles of induction, expels a similar quantity of the same fluid from the opposite unelectrified surface, and renders that negative, in the same degree as the inside is positive. Being negative, it increases the attraction of the inner surface for the opposite species of fluid, and another spark is received, which again expels an additional quantity of the same species of fluid from the outside, and thus the two surfaces continue to act upon each other reciprocally, though with constantly diminishing power, until the jar is charged.

The reason also is plain, why the outside of the jar must be uninsulated; since it is only in such case, that the foregoing

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How long may the charge of a jar be retained? How is it usually dissipated? How may the waste be prevented? Explain the accumulating power of the jar, on the principle of induction. What effect has the *thickness of the jar on this* power? Trace the process of charging a jar.

process of induction can take place: and we readily see why a series of jars may be charged from the portion of electricity which is expelled from the outside of the first jar.

394. When a jar is charged negatively from the rubber, just the opposite process in all respects takes place, the outside becoming positive by induction and reacting upon the inside. The case mentioned in Art. 392. (6.) where two jars differently charged cannot be discharged except their outer surfaces be in conducting communication, will be readily understood; for it is impossible for the equilibrium to be restored by the union of the electricities on the inside, while the outside remains electrified. If we could suppose this to take place for a moment, and the electricity within to be restored to its natural state, it would again be immediately decomposed by the inductive influence of the electrified coating without.

395. The phenomena of the Leyden Jar may be equally well explained, by substituting the terms vitreous and resinous, instead of positive and negative, on the supposition of two fluids, since the principles of induction apply equally well to both hypotheses. Thus, it is as easy to suppose that the resinous electricity is induced upon the outside by the attraction of the vitreous electricity within, as it is to suppose that the outside becomes negative by the loss of a portion of its natural share; and the necessity of the outer surface being uninsulated, is as apparent in the one case as in the other.

CHAPTER III.

OF ELECTRICAL LIGHT, OF THE BATTERY, AND OF THE MECHANICAL AND CHEMICAL AGENCIES OF ELECTRICITY.

Electrical Light.

396. *Electrical light appears whenever the fluid is discharged, in considerable quantity, through a resisting medium.*

Accordingly, no light is perceived when electricity flows freely through good conductors; but if such conductors suffer

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Why must the outside of a jar be uninsulated before it will receive a charge? Explain the process when the jar is charged negatively from the rubber? Explain the reason why two jars, differently charged, cannot be discharged unless the outsides are in conducting communication. Can the facts be explained on either hypothesis?

any interruption, as by the intervention of a space of air, or even of an imperfect conductor, then the attendant light becomes manifest. We shall best learn the properties of the electrical spark, by attending to a variety of experiments in which it is exhibited.*

A glass tube rubbed with black silk, which has been smeared with a little electrical amalgam, will yield copious sparks and flashes of light. The tube should be warm, dry, and smooth, and of a size not less than two feet in length, and three fourths of an inch in diameter.

The electrical machine, when in vigorous action, affords brilliant circles and streams of light. In order to render the light afforded by turning the machine abundant, several practical expedients are necessary. All parts of the machine must be dry and warm, (but not hot.) It is useful to rub very freely the glass plate or cylinder, with an old silk handkerchief. Black spots or lines that collect on the glass, especially when the amalgam is new, are to be carefully rubbed off, and should dust or down collect on the amalgam of the rubber, this must be removed. The action of the cylinder will be increased by the following process: smear the bottom of the cylinder with a thin coat of tallow; then turn the machine until the tallow is all taken up by the rubber and flap. The pores of the flap will then become filled with tallow, it will apply itself more closely to the cylinder, and the supply of electricity will become more copious. A convenient method of recruiting the action of the machine, is to coat a circular disk of paste board or leather with amalgam, and to apply it to the glass plate or cylinder while the machine is turning.

If the chain be removed from the rubber to the prime conductor, so that the former shall be insulated and the latter uninsulated, on bringing the ends of the fingers near the rubber, a stream of diluted light will pass between the fingers and the rubber.

397. *The electric spark passes, with increased facility, through rarefied air; and the distance to which it will pass between two conductors, is augmented as the rarefaction is made more complete.*

Electrical Light.—When does electrical light make its appearance? Does it appear in the passage of electricity through good conductors, or through bad? How may a glass tube be made to emit light? How may the electrical machine be made to give sparks most freely? How does the electric spark pass through rarefied air?

* In experiments on electrical light, the room is supposed to be dark. They appear to best advantage in the night.

Instead of the distance of five or six inches, which is the limit of the spark from the prime conductor of an ordinary machine in the open air, the spark will pass through the space of eighteen inches or more, in an exhausted receiver. If a pointed wire, terminating in a knob above, be introduced into the top of a tall receiver, and the receiver be placed on the plate of the air pump, on connecting the knob of the wire with the prime conductor, and turning the machine, a brush of light only will appear at the extremity of the wire; but, on exhausting the air, this brush will enlarge, varying its appearance and becoming more diffused as the air becomes more rarefied, until at length the whole receiver is pervaded by a beautiful bluish light, changing its color with the intensity of the transmitted electricity, and producing an effect which, with an air pump of considerable power, is pleasing in the highest degree.

When a charged jar is placed under the receiver of an air pump, as the exhaustion proceeds, a luminous current flows over the edge of the jar, between the opposite sides, until the equilibrium is restored. Electric light exhibits a very beautiful appearance, as it passes or *flows* through the *Torricellian Vacuum*.* The color is of a very delicate bluish or purple tinge, and the light pervades the entire space. But the most pleasing exhibitions of this kind are made by forming an artificial atmosphere of vapor in the Torricellian tube. Ether or alcohol, passes into the state of vapor when the pressure of the atmosphere is removed; and accordingly, on introducing a drop of one of these fluids, into the Torricellian vacuum, it immediately evaporates and fills the void. If, now, a strong spark be passed from the prime conductor through this vapor, the spark will exhibit various colors; in ether, it is an emerald green, or mingled red and green; in alcohol it is red or blue; but the colors vary somewhat with the distances at which they are seen, and with the temperature of the vapor.

398. *In condensed air*, on the contrary, the spark passes with greater difficulty than ordinary. In such case, also, its whiteness and brilliancy are augmented, and its course is zigzag.

To what distance will the electric spark pass in an exhausted tube? Relate the experiment of electrifying the receiver of an air pump, while the exhaustion is going on. What is the appearance when a charged jar is placed under the receiver of an air pump? How does the spark flow through the Torricellian vacuum? How when made to pass through the vapor of ether, alcohol, &c.? What is the appearance of the spark in condensed air?

* This is the vacuum produced by means of quicksilver in an inverted glass tube, as the barometer, Art. 295.

These appearances are even exhibited by passing a spark through *confined* air, of only the ordinary density. The colors of the spark are pleasingly varied by passing it, in a condensed form, as in the Leyden Jar, through media of different kinds. The experiment is performed by making the given body form a part of the circuit of communication, between the inside and outside of the Leyden Jar. A ball of ivory in this situation exhibits a beautiful crimson; an egg, a similar color, but somewhat lighter; a lump of sugar gives a very white light, which remains for some time after the spark has passed; and fluor spar exhibits an emerald green light, or, in some cases, a purple light, which also continues to glow in the dark for some seconds. The great intensity of the light is shown by the strong illumination which the sparks in the jar communicate to bodies slightly transparent. Thus, an egg has its transparency greatly increased; and if the thumb be placed over the space which separates the two conducting wires that communicate with the two sides of the jar respectively, the illumination is so powerful, that the blood vessels, and interior organization of the organ may be distinctly seen.

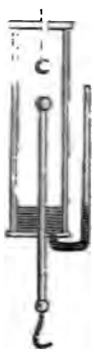
399. Metallic conductors, if of sufficient size, transmit electricity without any luminous appearance, provided they are perfectly continuous; but if they are separated in the slightest degree, a spark will occur at every separation. On this principle, various devices are formed by pasting a narrow band of tin foil on glass, in the required form, and cutting it across with a pen-knife where we wish sparks to appear. If an interrupted conductor of this kind be pasted round a glass tube, in a spiral direction, and one end of the tube be held in the hand, and the other be presented to an electrified conductor, a brilliant line of light surrounds the tube, which has been called the spiral tube, or diamond necklace. By enclosing the spiral tube in a large cylinder of colored glass, the sapphire, topaz, emerald, and other gems may be imitated. Words, flowers, and other complicated forms, are also exhibited nearly in the same manner, by a proper disposition of an interrupted line of metal, on a flat piece of glass.

400. *The light of the electric spark is not a constituent part of electricity, but arises from the sudden compression of the air, or other medium through which it passes.*

What appearance does the spark give when passed through ivory, egg, sugar, and fluor spar? What facts shew the great intensity of the light? On what principle is electricity made to exhibit words, flowers, &c.? What is the origin of the light which accompanies electricity?

It is well known, that air is capable of affording a spark by sudden compression. There is a kind of match constructed on this principle, in which a small portion of air, contained in a close cylinder, being suddenly compressed by forcing down a piston, yields a spark sufficient to light a quantity of tinder at the bottom of the cylinder. Now it is found by actual experiment, that electricity has the power of condensing air. This may be shown by means of a small instrument called *Kinnersley's Air Thermometer*. It consists of a glass tube, closed air-tight at the two ends by brass caps, through each of which passes a movable wire, terminated within by a small ball. Through the lower cap is inserted a small glass tube, open at both extremities, and turned upwards parallel to the cylinder. Into this tube is introduced a quantity of water sufficient to cover the bottom of the cylinder, and of course to rise a little way into the tube. The two balls being set at some distance from each other, and a spark from the Leyden Jar being passed between them, the air within is suddenly rarefied, and the water ascends in the tube, and again descends, when the explosion is over. This sudden rarefaction of a portion of air before the electric spark, must cause a sudden and powerful compression in the portions of air immediately adjacent. The immense velocity of the spark must greatly increase the resistance, and of course the force of compression. This appears to be an adequate cause for the production of the light that accompanies the electric discharge, and hence we conclude, that light is not inherent in the fluid itself. The greater density and brilliancy of the spark in condensed air, and its feebleness and diffuseness in a rarefied medium, are facts which accord well with the supposed origin; and the *zigzag* form of the spark when long, or when passing through condensed air, is well explained by the same theory. For the electric fluid in its passage through the air, condenses the air before it, and thus meets with a resistance which turns it off laterally; in this direction it is again condensed, and has its course again changed; and so on, until it reaches the conductor towards which it is aiming. The zigzag form of lightning is accounted for on this principle.

Fig. 90.



Electrical light is found by optical experiments to have precisely the same nature with the light of the sun, being like this

Describe Kinnersley's Air Thermometer. What is the cause of the zigzag form of the spark? Has electric light the same nature with solar light?

resolved into various colors by the prism, and possessing other properties, to be described under the head of Optics, which identify it with solar light.

Battery.

401. *An electric battery consists of a number of Leyden Jars so combined, that the whole may be either charged or discharged at once.*

Very large jars cannot be obtained; it is rare to find one more than two feet high, by one and a half in diameter. Yet some of the mechanical effects of electricity, to be described hereafter, require a much greater accumulation of the fluid than can be obtained from any single jar. The battery is constructed as follows. Large jars, twelve or fourteen inches high, by five or six inches in diameter, are coated like ordinary Leyden Jars. Twelve of these constitute a battery sufficiently powerful for most purposes, but the power of the battery may be carried to an indefinite extent by increasing the number of jars. When the number is twelve, they are placed four in a row in a box, the bottom of which is coated with tin-foil, by means of which the outsides of the jars are all in conducting communication. Each jar is separated from the rest by a slight partition of wood. To connect the insides of the jars, their knobs are joined by large brass wires. It is obvious, therefore, that the battery is equivalent to a single jar of enormous size comprehending the same number of square feet.

The object of the battery is to accumulate a great *quantity* of the electric fluid, which is in proportion to the extent of surface; the *intensity*, or elastic force, as indicated by the quadrant electrometer, is no greater in the battery when charged, than in a single charged jar. The battery, like the common jar, is charged by bringing the inside into communication with the prime conductor of an active and powerful electric machine: it is discharged, as usual, by forming a connexion between the inside and outside, commonly by means of the dicharging rod.

402. The largest machine and battery hitherto constructed, were made for the Teylerian museum, at Haarlem. It consists of two circular plates of glass, each five feet five inches in di-

Battery.—Of what does it consist? How constructed? How are the jars connected on the inside? How on the outside? What is the object of the battery? How does the intensity compare with that of a common jar? How is the battery charged and discharged?

ameter. The prime conductor consists of several pieces, and is supported by three glass pillars, nearly five feet in length The force of two men is required to work the machine; an when it is required to be put in action for any length of time four are necessary.

At its first construction, nine batteries were applied to it, eacl having fifteen jars, every one of which contained a square foo of coated glass ; so that the grand battery, formed by the com bination of all these, contained one hundred and thirty five feet As examples of the great power of the Teylerian machine, w may mention the following: it charged a Leyden Jar by turnin the handle half round,—a charge which the jar would receiv and lose by discharging itself spontaneously, eighty times in minute. A single spark from the conductor melted a conside able length of gold leaf. A spark, or zigzag stream of fir would dart from the prime conductor to a neighboring condu tor to the distance of ten feet. A wire three eighths of an inc in diameter, was found to be sufficient to transmit the whol charge of the prime conductor, but the wire would give sma sparks to a conductor brought near to it. The sphere of influ ence (Art. 379.) extended to the distance of forty feet, so a sensibly to affect the pith ball electrometer. The *spider w* sensation (or the peculiar sensation resembling that of th spider's web) which is experienced by holding an excited gla tube to the face, was felt by bystanders to the distance of eigl feet from the machine.

Mechanical Effects of Electricity.

403. *The sound produced by an electric discharge is ascrib to the sudden collapse of the air, which has been displaced by t passage of the electric fluid.*

Hence the sound is greater in proportion to the quantity a intensity of the charge. A battery, when fully charged, give a loud explosion.

404. *Imperfectly counducting substances, through which powerful electric charge is passed, are torn asunder with more less violence.*

Describe the great machine at Haarlem. What effects were produc by this machine in charging a jar—in melting gold leaf—length of tl spark? How far did the sphere of influence extend? How far was tl spider web sensation felt? What is the origin of the *sound* which ac companies an electrical discharge? How are imperfect conductors a *fected by* a powerful discharge?

A large Leyden Jar is sufficient for exhibiting some of these mechanical effects: others require the power of the Battery. When the charge is passed through a thick card, or the cover of a book, a hole is torn through it, which presents the rough appearance of a bur on each side. By means of the Battery, a quire of strong paper may be perforated in the same manner; and such is the velocity with which the fluid moves, that if the paper be freely suspended, not the least motion is communicated to it. (See Art. 29.) Pieces of hard wood, of loaf sugar, of stones, and many other brittle non-conductors, are broken, or even torn asunder with violence, by a powerful charge from the battery. If two wires be introduced into a soft piece of pipe clay, and a strong charge be passed through them, the clay will be curiously expanded in the interval between the wires.

The expansion of *fluids* by electricity is very remarkable, and productive of some singular results. When the charge is strong, no glass vessel can resist the sudden impulse. Beccaria inserted a drop of water between two wires, in the center of a solid glass ball of two inches diameter; on passing a shock through the drop of water, the ball was dispersed with great violence. In like manner, by the sudden expansion of a small body of confined air, strongly electrified, explosions may be produced, and bodies that resist its expansion are projected with violence. Even good conductors, when minutely divided, are expanded by electricity. Thus, mercury confined in a capillary glass tube, will be expanded with a force sufficient to splinter the tube.

Chemical Effects of Electricity.

405. *By means of Electricity, more or less accumulated, a variety of chemical effects may be produced; such as the combustion of inflammable bodies, the oxidation, fusion, and even combustion of metals, the separation of compounds into their elements, or the union of elements into compounds.*

Ether and alcohol may be inflamed by passing the electric spark through them; nor is the effect diminished by communicating the spark by means of a piece of ice or any other cold medium. The finger may be conveniently employed to inflame

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How are pieces of hard wood, loaf sugar, stones, &c. affected by a charge from the battery? What effects result from the sudden expansion of fluids by the electric charge? Does this effect extend even to good conductors? State the *chemical effects* produced by electricity. What combustibles may be inflamed?

these substances. Phosphorus, resin, and other solid combustible bodies, may be set on fire by the same means; gunpowder and the fulminating powders may be exploded; and a candle may be lighted. Gold leaf and fine iron wire may be burned by a charge from the battery. Wires of lead, tin, zinc, iron, copper, platina, silver and gold, when subjected to the charge of a very large battery, burn with explosion and are converted into oxides.

The same agent, moreover, is capable of reviving these oxides; that is, restoring them to the state of pure metals. By a similar contrariety of properties, water is decomposed into its gaseous elements, and the same elements are reunited to form water; and the constituent gases of atmospheric air are, by passing a great number of electric charges through a confined portion of air, converted into nitric acid.

Motions of the Electric Fluid.

406. *The velocity of the electric fluid is apparently instantaneous.* A circuit of four miles has been formed, by means of wire, between the inside and outside of a Leyden Jar, and no perceptible interval was occupied during the discharge. Analogy, however, would lead us to believe that Electricity, like light, is progressive in its motions, but that it moves with a velocity too great to be measured, except for intervals of immense extent.*

407. *The electric fluid, in its route, selects the best conductors.* The Leyden Jar may be discharged with a wire held in the hand, without the insulating handle used in the Discharging Rod; since metallic wire is a better conductor than the hand, and the fluid will take its route through that in preference to the hand. But if a wooden discharger be substituted for the wire, the shock will be felt, since animal substances are better conductors than wood. It is necessary to remark, however, that when the charge is very intense, or the quantity great, as in the Battery, then some portion of the fluid will escape from the

What substances may be burned with explosion? How does electricity act both to decompose and to reunite the elements of bodies? Is the velocity of the electric fluid progressive or instantaneous? What bodies does the electric fluid select in its route?

* The velocity of light appears to be instantaneous, for such distances as four miles; but when such intervals are taken as the diameter of the earth's orbit, light is found to have a progressive velocity of 192,500 miles per second. If, therefore, electricity actually moves with a progressive velocity like that of light, still the time occupied in traversing the space of four miles would be inappreciable, since it would equal only about the fifty thousandth part of a second.

discharging wire and pass through the hand. In such cases, therefore, it is prudent to make use of the Discharging Rod.

Lightning, in striking a building, usually takes a course which indicates the preference of the fluid for the best conductors.

408. *The electric fluid will sometimes take a shorter route through a worse conductor, in preference to a longer route through a better conductor.* The spark will pass through a short space of air, instead of following a small wire thirty or forty feet. The preference of the shorter route is sometimes indicated in taking the electric shock. While one person is receiving the shock from the Leyden Jar, another may grasp his arm without feeling the least effect from the charge.

409. *The course of the charge is frequently determined by the influence of points, either in dissipating or in receiving the fluid.* Sharp points connected with the best conductors, greatly favor the dispersion of the fluid during its passage, and sharp pointed conductors draw the charge towards them, from a great distance around. The finest needle, held in the hand towards the knob of one of the jars of a charged battery, will silently discharge it in a few seconds; and if we apply one hand to the outside of a Leyden Jar, and with the other bring a fine needle to the knob of the Jar, only a comparatively feeble shock will be felt, the charge being rapidly dissipated while the needle is approaching the knob.

CHAPTER IV.

OF THE EFFECTS OF ELECTRICITY UPON ANIMALS, AND OF THE LAWS OF ELECTRICAL PHENOMENA.

410. We have already several times incidentally adverted to the shock communicated to the animal system, when it is brought into the electric circuit, so that the charge passes through it. We now propose to consider this interesting part of the subject more particularly.

The Electric Shock is received, whenever the animal system is made a part of the conducting communication between the inside

Is such a preference ever manifested by lightning? What preference does the fluid manifest for the shortest route? What influence have *points on the course of the charge?*

and outside of a charged Leyden Jar. A convenient method of administering the shock is to place the charged jar on a table, resting immediately on a metallic plate,* as a plate of tin, lead, or copper; then grasping a metallic rod in each hand, touch one of them to the plate, and the other to the knob of the Jar, and a sudden convulsion of the limbs or the breast will be experienced, more or less violent according to the strength of the charge. The effect is greatly heightened by feelings of dread or apprehension, and it may be resisted to a considerable degree by voluntary effort. A slight charge affects only the fingers or the wrists; a stronger charge convulses the large muscles above the arm-pits; a still greater charge passes through the breast and becomes in some degree painful. Electricians, however, have frequently ventured upon charges sufficiently powerful to convulse the whole frame.

411. *The shock may be communicated to any number of persons at once.* This is usually effected by their joining hands, while the first in the series holds one of the metallic rods, with which he touches the plate, or outside of the Jar, and the last in the series holds the other rod, with which he touches the knob of the Jar, at which instant the whole number receive the shock at the same moment, and that however extensive the circle of persons may be. The charge of a large battery is sufficient to destroy human life, especially if it be received through the head. By standing on the *Insulating Stool*, which is a stool with glass feet, a person becomes an insulated conductor, and may be electrified like any other insulated conductor. A communication being made with the machine, the fluid pervades the system, but excites hardly any sensation except a prickling of the hair, which at the same time rises and stands erect; for the hairs being similarly electrified mutually repel each other.

412. While in this situation, the human system exhibits the same phenomena as the prime conductor when charged; that is, it attracts light bodies, gives a spark to conductors brought near it, and communicates a slight shock to another person who re-

When is the electric shock received? What is a convenient method of receiving the shock? How is the effect heightened? How do charges of different degrees of intensity affect the system? How is the shock communicated to a number of persons at once? How would the shock received from a very powerful battery affect the human system? What are the effects of the charge received on the insulated stool? What electrical effect does the body exhibit when thus electrified?

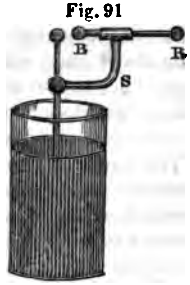
* *It is safer to employ such a plate than to bring the conducting rod immediately into contact with the outside coating of the Jar; for, in such case, persons unaccustomed to receive the shock, are apt to overturn the Jar and break it.*

ceives the spark from it. Indeed the same shock is felt by both parties.

By means of the insulating stool, the most delicate shocks may be given; for the charge may be drawn off from any part, by imperfect conductors. Thus, a pointed piece of wood will draw off the charge from the eye, in a manner so gentle, as to secure that tender organ against any possibility of injury. By a variety of conductors, of different powers, and by points and balls, the sensations may be accommodated, with much delicacy, to the state of the patient, or to the nature of the affected part.

413. The shock may be communicated directly to any individual part of the system, without affecting the other parts, by making that part form a portion of the electric circuit, between the inside and outside of a Leyden Jar. Thus, let it be required to electrify an arm. Two *directors*, (consisting of wires terminating in brass knobs, and insulated by glass handles,) are connected by chains with the knob and the outside coating of a charged Jar; then, on applying one of the directors to the hand, and the other to the naked shoulder, the arm is convulsed. In cases where the patient requires only a moderate shock, the charge is regulated by a contrivance attached to the Jar, called *Lane's Discharging Electrometer*, represented in Fig. 91. S is a stick of solid glass; B, R, two brass knobs, connected by a wire, which slides back and forth in such a way that it may be set at any required distance from the knob of the Jar. If the ball B be set in contact with the knob, then, on touching the ball and the outer coating of the Jar, the entire charge of the Jar is received; but by removing the ball B from the knob, the half, fourth, or any aliquot part of the charge, may be taken, and by continually charging the Jar while the ball remains at this constant distance from the knob, successive shocks of any required strength may be taken.

Fig. 91



414. Soon after the discovery of the Leyden Jar, commenced the application of Electricity to *Medicine;* and Medical Electricity became thenceforth a distinct branch of the science.

Describe the mode of giving very gentle shocks. Also the mode of electrifying any particular part, as the arm. Describe Lane's Electrometer. How is it used in giving a succession of shocks of any required strength? When was electricity first applied to medicine? What was the first cure?

The first cure said to have been effected by this agent, was upon a paralytic. Electricity shortly became very celebrated for the cure of this disorder, and patients flocked in great numbers to the practitioners of this branch of the profession. As usual, the effects of this new remedy were greatly exaggerated, and it was widely extolled, not only for the cure of palsy, but of all other diseases. It was even pretended that the virtues of the most valuable medicines might be transferred into the system through the medium of electricity, preserving their specific properties in the same manner as when taken by way of the stomach. Preparations of this kind were called *Medicated Tubes*. Pavati, an Italian, and Winkler, a German, were especially celebrated for this species of practice. The mode was to enclose the medicines in a glass tube, then to excite the tube, and with it to electrify the patient. In this way, it was said, the healing virtues of the medicines were communicated to the system in a manner at once efficacious and agreeable.

415. Pretensions so extravagant could not long be sustained, and the natural consequence was that the use of electricity in medicine soon fell into great neglect, and has remained in this situation to the present time. There are, however, certain properties inherent in this agent, which deserve the attention of the enlightened physician, and inspire the hope that, in judicious hands, it may still be auxiliary to the healing art. First, the great activity of this agent, particularly the facility and energy with which it can be made to act upon the nervous system, indicate that it has naturally important relations to medicine. The power of being applied, locally, to any part of the system, renders it a convenient application in cases where other local remedies cannot be administered. Secondly, the acknowledged property of electricity to promote the circulation of fluids through capillary tubes, Art. 385. (7.) suggests the probability of its being efficacious in promoting the circulation of the fluids of the animal system, and in increasing the quantity of insensible perspiration. Thirdly, in the history of medical electricity are recorded well attested cures, effected by means of electricity, of such diseases as palsy, rheumatism, gout, indolent tumors, deafness, and a variety of other disorders.

What pretensions were made respecting the medicinal virtues of electricity? Describe the Medicated Tubes. What was the mode of administering medicines by means of them? What changes occurred in the degrees of reputation of this medicine? What properties of electricity *lead us* to infer medicinal virtues? What diseases has it been supposed *to cure?*

Cause of Electrical Phenomena.

416. For the sake of convenience, and for the purpose of avoiding repetition and circumlocution, we have made occasional use of the phrase *electric fluid.* It may be proper now to inquire whether there are any just grounds for supposing such a fluid or fluids to be present in electrical phenomena.

There are two modes by which the existence of such a fluid may be rendered probable: the first is, by showing that such a supposition is conformable to the analogy of nature; the second is, by proving that the agent of electrical phenomena exhibits the properties of a fluid.

417. First, *there are some reasons derived from analogy for believing in the existence of an electric fluid.* (1.) The reasons in favor of supposing that light and heat are caused by the agency of peculiar fluids, (arguments, however, that we cannot discuss here,) which have induced a general belief, are, for the most part, equally applicable to electricity. (2.) In the present state of our knowledge, the most subtile of all fluids, indeed the most attenuated form of matter, is hydrogen gas, of which one hundred cubic inches weigh only [illegible] grains, which is nearly fourteen times lighter than common air. But at no distant period, means had not been devised by mankind for proving the materiality of common air, nor even of indentifying the existence of the other gases which now bear so conspicuous a part in experimental philosophy. But as knowledge and experimental researches have advanced, a series of fluids still more subtile than air, have come to light, until we have reached a body nearly fourteen times lighter than air, at which, at present, the series stops. Is it probable, however, that nature stops in her processes of attenuation precisely at the point where, for want of more delicate instruments, or more refined and powerful organs of sensation, our methods of investigation, and powers of discrimination, come to their limit? An examination of the general analogies of nature will lead us to think otherwise. The subordination which exists among the different classes of bodies that compose the other departments of nature, is endless, or at least indefinite. In the animal creation, for example, beginning with the mammoth or the elephant, we descend through numerous tribes to the insect which is barely visible in the sunbeam. Before human ingenuity had devised means

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***Cause of Electrical Phenomena.*—In what two modes may the existence of such a fluid as the electric be rendered probable? State the argument from analogy.**

of aiding the powers of vision, the naturalist might have fixed this as the limit of the animal creation. But the invention of the microscope has carried the range of human vision immeasurably farther; and at each successive improvement in that instrument, new tribes of insects or animalcules have been revealed to the eye, still more and more attenuated. A similar subordination might be found in the vegetable kingdom, and in the organic structure of both animals and vegetables.

To apply this analogy to the case before us, we begin the series of inorganic bodies with platinum, and descend through classes of bodies constantly diminishing in density, until we come to ether, the lightest of liquids, and on the confines of those bodies which are invisible to the eye, and manifest only by the effects which they produce. By modern discoveries the series has been extended to hydrogen, a body 247,000 times lighter than platinum. Here for the present we pause, standing in the same relation with respect to any fluids that may lie beyond, that the ancients stood with respect to common air, and all other aeriform fluids.

Considerations of this nature lead us to believe that there are, in nature, fluids more subtile than hydrogen; and, such being the fact, we can hardly resist the belief, that Heat, Light, and Electricity, are bodies of this class,—bodies which make themselves known to us by the most palpable and energetic effects, although their own constitution is too subtile and refined for our organs to recognise, or our instruments to identify them as material.

418. Secondly, in addition to the foregoing presumptions in favor of the supposition that electricity is a peculiar fluid, *it exhibits in itself the properties of a fluid.* The rapidity of its motions, the power of being accumulated, as in the Leyden Jar, its unequal distribution over the surfaces of bodies, its power of being confined to the surfaces of bodies by the pressure of the atmosphere, its attractions and repulsions, are severally properties which we can hardly ascribe to any thing else than an elastic fluid of the greatest tenuity.

But granting the presence of an elastic fluid in electrical phenomena, it remains to be determined whether, according to the hypothesis of Franklin, these phenomena are to be ascribed to the agency of a single fluid, or whether, according to that of Du Fay, they imply the existence of two distinct fluids. The

Arguments for the materiality of light and heat applicable to electricity. What are the grounds of presumption of the existence of very subtile fluids, lighter than hydrogen gas?

numerous facts with which the learner has been made acquainted in the preceding pages, will fit him to appreciate the evidence offered in favor of or against these hypothoses respectively.

419. The principles of each hypothesis have been already explained, (see Art. 373.) and they have been rendered familiar by repeated application. It will be recollected, that they concur in supposing that all bodies are endued with a certain portion of electricity, called their *natural share*, in which the fluid, whether single or compound, is in a state of perfect equilibrium; and that, in the process of excitation, this equilibrium is destroyed. But here the two views begin to diverge: the one supposes that this equilibrium is destroyed in consequence of the separation of *two fluids*, which, like an acid and an alkali combining to form a neutral salt, exactly neutralize each other by mutual saturation, but which, when separated, exhibit their individual properties; the other, that the equilibrium is destroyed, like that of a portion of atmospheric air, by greater or less exhaustion on the one side, or condensation on the other. In the former case, moreover, the equilibrium is restored by the reunion of the two constituent fluids; in the latter, by the movement of the redundant portion to supply the deficient, as air rushes into the exhausted receiver of an air pump.

It is a remarkable fact, that nearly every electrical phenomenon may be perfectly explained in accordance with either hypothesis; nor is it agreed, that an *experimentum crucis** has yet been found.

420. One of the latest advocates of the hypothesis of a single fluid is Mr. Singer, an able practical electrician; and the most distinguished defender of the doctrine of two fluids is M. Biot. In support of the former doctrine are offered such arguments as the following. (1.) Its greater *simplicity*. It is supposed to be more comformable to the Newtonian rule of philosophizing, "to ascribe no more causes than are just sufficient to account for the phenomena." The known frugality of Nature, in all her operations, might lead us to suppose, that she would not

In what particulars do the two hypotheses concur? In what do they differ? When, according to each hypothesis? Does each explain all the facts? What is an experimentum crucis? State the arguments in favor of Franklin's hypothesis. What is inferred from its simplicity?

* The "experimentum crucis," is a phrase introduced by Lord Bacon, implying a fact which can be explained on one of two opposite hypotheses, and not on the other. The figure is derived from a cross set up where two roads meet, to tell the traveller which road to take.

employ two agents to effect a given purpose, when a single agent would be competent to its production. This argument, however, cannot be applied, either where one cause is *not* sufficient to account for the phenomena, or where there is direct proof of the existence of more agents than one. (2.) The appearance of a *current*, circulating from the positive to the negative surface, analogous to the passage of air of greater density into a rarefied space. This point is much insisted on by Singer, and numerous examples are brought forward, where the progress of such a current is manifest to the senses. Thus, the flame of a candle, brought into the circuit between the inside and outside of a Leyden Jar, is, on the discharge of the Jar, bent towards the negative side; a pith ball, under similar circumstances, moves in the same direction; when a charged Jar is placed under the receiver of an air pump, and the air is exhausted, a luminous cloud flows from the positive to the negative side, in whichever way the Jar is electrified. None of these arguments, however, are found to be conclusive, for the mechanical effects, which are here ascribed to an elastic fluid, that is, the electric fluid, flowing towards the negative side, can all be accounted for, either upon the principles of attraction and repulsion, common to both hypotheses, or from the mechanical impulse of a current of air. The electric spark passing instantaneously, or at least with a velocity entirely inappreciable, it is impossible to determine its direction.

The fact that *bodies negatively electrified repel each other*, (Art. 374.) is a strong argument against the truth of the hypothesis under consideration. It is not difficult to conceive that a self repellent fluid should communicate the same property to two pith balls in which it resided; but that the mere *deficiency* of the fluid should produce the same effect is incredible. This fact drove Æpinus, (a celebrated German electrician, who brought this hypothesis to the test of Mathematical demonstration,) to the necessity of supposing that *unelectrified matter is self repellent*,—a supposition which is not only destitute of proof, but which is inconsistent with the general laws of nature, from which it appears that attraction and not repulsion exists mutually between all kinds of bodies. In the distribution of electricity upon surfaces differing in shape and dimensions, the fluid is found to arrange itself in strict accordance with hydrostatic

Are there any appearances of an electric current? What prevents us from determining the direction in which electricity moves? What is inferred from the fact that bodies negatively electrified repel each other? What property has been asserted of unelectrified matter?

principles, and that too in bodies negatively as well as positively electrified. Now that the privation, or mere absence of a fluid, should exhibit such properties of a present fluid, is inconceivable.

421. In favor of the doctrine of two fluids, the following arguments are urged. (1.) *Two opposite currents* are supposed to be sometimes indicated. Thus, (Art. 404,) a card perforated by a strong electric discharge, exhibits burs or protrusions on both sides. The appearance of the *electric spark*, passing between two knobs, is supposed by some writers to indicate the meeting of two fluids from opposite parts. When the spark is short, the whole distance between the two knobs through which it passes, is illuminated. But when the spark is long, those portions of it which are nearest to the knobs, are much brighter than the central portions. Near the knobs the color is white, but towards the center of the spark it is purplish. Indeed, if the spark is very long, the middle part of it is not illuminated at all, or only very slightly. Now this imperfectly illuminated part, is obviously the spot where the two electricities unite, and it is in consequence of this union, that the light is so imperfect. (2.) The two electricities are characterized by *specific differences*. The light afforded by the vitreous surface is different from that of the resinous; when the two opposite portions of the spark meet, as above, the place of meeting is only half the distance from the negative that it is from the positive side; the bur protruded from the card is larger in the direction of the vitreous than in that of the resinous fluid; and the two severally produce certain chemical effects in bodies which are peculiar to each. (3.) But the most conclusive argument in favor of two fluids, is the perfect manner in which this supposition accounts for the *distribution of electricity* on bodies of different dimensions. On the hypothesis that electrical phenomena are owing to the agencies of *two fluids, both perfectly incompressible, the particles of which possess perfect mobility, and mutually repel each other, while they attract those of the opposite fluid, with forces varying in the inverse ratio of the squares of the distances*,—on this hypothesis, M. Poisson, a celebrated mathematician of France, applied the exhaustless resources of the calculus, to determine the various conditions which electricity would assume in distributing itself over spheres, spheroïds, and bodies of

State the arguments in favor of the doctrine of two fluids. What indications are there of opposite currents? How do the appearances of the spark favor this doctrine? *By what specific differences are the two electricities characterized?*

[illegible] The results at which he arrived were such as [illegible] a very remarkable degree with experiment, and leave [illegible] that the hypothesis on which they were built is [illegible] any supposition involved in the hypothesis [illegible] consistent with established facts. (4.) Finally, author[illegible] present day, almost wholly on the side of the doc[illegible] two fluids,—an opinion which has constantly gained [illegible] with every new discovery in the science of [illegible], particularly in the department of Galvanism.

CHAPTER V.

OF ATMOSPHERICAL ELECTRICITY.—THUNDER STORMS.—LIGHTNING RODS.

422. Having learned the laws of Electricity from a great variety of experiments, the student is now prepared to look upon the works of nature, and to study the phenomena which the same agent produces there on a more extensive scale.

The atmosphere is always more or less electrified. This fact is ascertained by several different forms of apparatus. For the lower regions, it is sufficient to elevate a *metallic rod* a few feet in length, pointed at the top, and insulated at the bottom. With the lower extremity is connected an electrometer, which indicates the presence and intensity of the electricity. For experiments on the electricity of the upper regions, a kite is employed, not unlike a boy's kite, with the string of which is intertwined a fine metallic wire. The lower end of the string is insulated by fastening it to a support of glass, or by a cord of silk.

42[illegible]. The most powerful apparatus ever employed for atmospherical electricity, was constructed in France by M. de Romas. He prepared a kite seven feet long and three feet wide, and elevated [illegible] the height of five hundred and fifty feet. A cloud coming over, the most striking and powerful electrical phenomena presented themselves. Light straws, that happened to be on the ground near the string of the kite, began to erect themselves, and to perform a dance between the apparatus and the ground, after the manner of dancing images, as exhibited in

What [illegible] the [illegible] from the mode in which the fluid is distributed? On which side does a [illegible] concentrate?

Atmospherical Electricity.—What apparatus is employed to detect the presence of electricity in the atmosphere. Describe the apparatus of Romas,—state its effects.

ordinary electrical experiments. Art. 385. (5.) At length streams of fire began to dart to the ground, some of which were an inch in diameter, and ten feet long, exhibiting the most terrific appearance.

The foregoing facts evince the abundance of electricity in the atmosphere at particular periods; but experiments of a less formidable kind have been instituted, to ascertain the electrical changes of the air. For this purpose, Mr. Canton, an English philosopher, constructed an ingenious apparatus, which warned him of the presence of any unusual quantity of electricity, by causing it to ring a bell connected with the lower extremity of the apparatus.

424. Obvious as is the connexion between the phenomena of common electrical apparatus, and those exhibited in the heavens during a thunder storm, yet the identity of lightning with the electric spark, was not dreamed of by the early electricians. To Dr. Franklin, is universally conceded the merit of having established this fact, first by reasoning on just principles of analogy, and afterwards by actually bringing down the lightning from the skies. The resemblence between the appearances of lightning and electricity, were thus enumerated.

(1.) The zigzag form of lightning corresponds exactly in appearance with a powerful electric spark, that passes through a considerable interval of air.

(2.) Lightning most frequently strikes such bodies as are high and prominent, as the summits of hills, the masts of ships, high trees, towers, spires, &c. So the electric fluid, when striking from one body to another, always passes through the most prominent parts.

(3.) Lightning is observed to strike most frequently into those substances that are good conductors of electricity, such as metals, water, and moist substances; and to avoid those that are non-conductors.

(4.) Lightning inflames combustible bodies; the same is effected by electricity.

(5.) Metals are melted by a powerful charge of electricity: this phenomenon is one of the most common effects of a stroke of lightning.

(6.) The same may be observed of the fracture of brittle bodies.

(7.) Lightning has been known to strike people blind: Dr.

What appendage did Mr. Canton attach to his apparatus? Who discovered the identity between electricity and lightning? In what particulars do they resemble each other?

Franklin found that the same effect is produced on animals, by a strong electric charge.

(8.) Lightning destroys animal life: Dr. Franklin killed turkies, of about ten pounds weight, by a powerful electric shock.

(9.) The magnetic needle is affected in the same way by lightning and by electricity, and iron may be rendered magnetic by both causes. The phenomena therefore are strictly analogous, and different only in degree; but if an electrified gun barrel will give a spark, and produce a loud report at two inches distance, what effect may not be expected from 10,000 acres of electrified cloud? But (said Franklin,) to ascertain the accuracy of these ideas, let us have recourse to experiment. Pointed bodies receive and transmit electricity with facility; let therefore a pointed metallic rod be elevated into the atmosphere, and insulated; if lightning is caused by the electricity of the clouds, such an insulated rod will be electrified whenever a cloud passes over it; this electricity may then be compared with that obtained in our experiments.

425. Such were the suggestions of this admirable philosopher; they soon excited the attention of the electricians of Europe, and having attracted the notice of the king of France, the approbation he expressed, excited in members of the French Academy a desire to perform the experiment proposed by Franklin, and several insulated metallic rods were erected for that purpose. On the 10th of May, 1752, one of these, a bar of iron forty feet high, situated in a garden at Marly, became electrified during the passage of a stormy cloud over it; and, during a quarter of an hour, it afforded sparks, by which jars were charged, and other electrical experiments performed. During the passage of the cloud a loud clap of thunder was heard, so that the identity of these phenomena was thus completely proved. Similar experiments were made by several electricians in England.

426. Doctor Franklin had not heard of these experiments, and was waiting for the erection of a spire at Philadelphia to admit an opportunity of sufficient elevation for his insulated rod, when it occurred to him that a kite would obtain more ready access to the regions of thunder than any elevated building. He accordingly adjusted a silk handkerchief to two strips of cedar, placed crosswise; and having thus formed a kite, with a tail

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When was electricity first drawn from the clouds? When did Dr. *Franklin* perform his first experiments?

and loop, at the approach of the first storm, he repaired to a field accompanied by his son. Having launched his kite with a pointed wire fixed to it, he waited its elevation to a proper height, and then fastened a key to the end of the hempen cord, and attached this by means of a silk lace (which served to insulate the whole apparatus) to a post. The first signs of electricity which he perceived, was the separation of the loose fibres of the hempen cord: a dense cloud passed over the apparatus, and some rain falling, the string of the kite became wet; the electricity was then collected by it more copiously, and a knuckle being presented to the key, a stream of acute and brilliant sparks was obtained. With these sparks, spirits were fired, jars charged, and the usual electrical experiments performed. Thus was the identity of lightning and electricity, which had been indicated by so many analogies, now established by the most decisive experiments.

427. It is a matter of much importance to the science of Meteorology, (Art. 316.) to ascertain from what *source* atmospherical electricity originates. Among the known sources of this agent, none seems so probable as the evaporation and condensation of watery vapor. We have the authority of two of the most able and accurate philosophers, Lavoisier and La Place, for stating, that *bodies in passing from the solid or liquid state to that of vapor, and, conversely, in returning from the aeriform condition to the liquid or solid state, give unequivocal signs of either positive or negative electricity.*

Combustion is also attended with the evolution of electricity, and even the *friction* of opposite currents of wind, or of a high wind against opposing objects, probably generates more or less of the same agent. The production of electricity during evaporation and condensation, may be rendered evident by delicate instruments; as may that evolved during the friction of air. If the stem of a tobacco pipe be heated red hot, and a drop of water be introduced by way of the bowl, the jet of steam falling on a delicate electrometer, will indicate the presence of electricity.

It is obvious that a cause which produces only very feeble signs of electricity, in so small a quantity of vapor as that which arises from a single drop of water, may still be sufficient to occasion a vast accumulation of the same agent, in such a quantity of vapor as that which is daily ascending into the

How was the presence of electricity first indicated? From what source is atmospheric *electricity derived?* Is electricity evolved during combustion? *By what experiment* is it indicated during the production of vap

atmosphere. For it has been calculated, that more than two thousand millions of hogsheads of water are evaporated from the Mediterranean alone in one summer's day.

Thunder Storms.

428. The following are the *leading facts* respecting the electricity of the atmosphere in relation to this subject, and they are facts which have been established by numerous observers, of the most active and diligent class. Beccaria, an Italian electrician, continued his observations on the electricity of the atmosphere for fifteen years with great assiduity; and Cavallo, Read, Saussure, and others, prosecuted the same inquiries with similar zeal.

(1.) Thunder clouds are, of all atmospheric bodies, the most highly charged with electricity. But all single, detached, or insulated clouds, are electrified in greater or less degrees, sometimes positively and sometimes negatively. When, however, the sky is completely overcast with a uniform stratum of clouds, the electricity is much feebler than in the single detached masses before mentioned. And, since fogs are only clouds near the surface of the earth, they are subject to the same conditions;—a driving fog of limited extent, is often highly electrified.

(2.) The electricity of the atmosphere is strongest when hot weather succeeds a series of rainy days, or when wet weather succeeds a series of dry days; and during any single day, the air is most electrified when the dew falls before sunset, or when it begins to exhale near sunrise.

(3.) In clear steady weather, the electricity generally remains positive: but in falling or stormy weather, it is constantly changing from positive to negative, or from negative to positive.

Such are the circumstances of atmospherical electricity in general; next let us attend to the peculiar phenomena of thunder storms, chiefly as they are exhibited in our own climate.

In thunder storms there is usually a singular and powerful combination of all the elements,—of darkness, rain, thunder and lightning, and sometimes hail.

They occur chiefly in the hottest seasons of the year, and after mid-day; and are more frequent and violent in warm, than in cold countries.

Thunder Storms.—State the leading facts. Are thunder clouds found by experiment to be charged with electricity? How is the electricity of single detached clouds compared with a uniform stratum covering the face of the sky? What is said of the electrical state of fogs? What days are most electrical? What times of day? What kind of electricity prevails in clear weather, and what in falling weather? What combination of the elements do we observe in a thunder storm?

In this state, (Connecticut,) thunder storms usually come from the west, either directly, or from the north-west or south-west; but occasionally from the east.

Violent thunder and lightning are frequently observed in volcanoes and water spouts.

Thunder storms sometimes descend almost to the surface of the sea, and fall upon the sides of mountains; in which case they are extremely violent.

We occasionally observe the following circumstances succeed each other in regular order: first a vivid flash of lightning,—then a loud peal of thunder,—and, after a short interval, a sudden fall of rain, which sometimes stops as suddenly as it began.

429. There are in thunder storms evidently two distinct classes of phenomena to be accounted for. The first class consists of the common elements of a storm,—clouds, wind, and rain; the second, of thunder and lightning. The following proposition embraces, in our view, the true explanation of both these classes of phenomena:—

The storm itself, including every thing except the electrical appearances, is produced in the same manner as other storms of wind and rain; and the electricity, and of course the thunder and lightning, is owing to the rapid condensation of watery vapor.

We do not, therefore, consider electricity as the *cause*, but as the *consequence* of the storm; or as a concomitant of the clouds, wind, and rain.

Lightning Rods.

430. Dr. Franklin had no sooner satisfied himself of the identity of electricity and lightning, than, with his usual sagacity, he conceived the idea of applying the knowledge acquired of the properties of the electric fluid, so as to provide against the dangers of thunder storms. The conducting power of metals, and the influence of pointed bodies, to collect and transmit the fluid, naturally suggested the structure of the Lightning Rod. The experiment was tried and has proved completely successful; and probably no single application of scientific knowledge ever secured more celebrity to its author.

At what season of the year are thunder storms most violent? From what direction do they come? Are they ever observed in volcanoes and water spouts? What two classes of phenomena are to be distinctly accounted for? Enunciate the proposition that expresses the cause of thunder storms. *Lightning Rods.*—Who first suggested their use?

431. Lightning rods are at present usually constructed of wrought iron, about three fourths of an inch in diameter. The parts may be made separate, but, when the rod is in its place, they should be screwed together so as to fit closely, and to make a continuous surface, since the fluid experiences much resistance in passing through links and other interrupted joints. At the bottom the rod should terminate in two or three branches, going off in a direction from the building. The depth to which it enters the earth should not be less than five feet; but the necessary depth will depend somewhat on the nature of the soil: wet soils require a less, and dry soils a greater depth. In dry sand it must not be less than ten feet; and in such situations, it would be better still to connect, by a convenient conducting communication, the lower end of the rod with a well or spring of water. It is useful to fill up the space around the part of the rod that enters the ground, with coarsely powdered charcoal, which at once furnishes a good conductor, and preserves the metal from corrosion. The rod should ascend above the ridge of the building to a height determined by the following principle: that *it will protect a space in every direction from it, whose radius is equal to twice its height.* It is best, when practicable, to attach it to the chimney, which needs peculiar protection, both on account of its prominence, and because the products of combustion, smoke, watery vapor, &c. are conductors of electricity. For a similar reason a kitchen chimney, being that in which the fire is kept during the season of thunder storms, requires to be especially protected. The rod is terminated above in three forks, each of which ends in a sharp point. As these points are liable to have their conducting power impaired by rust, they are protected from corrosion by being covered with gold leaf; or they may be made of solid silver or platina. Black paint being made of charcoal, forms a better coating for the rod than paints made of other colors, the basis of which are worse conductors. The rod may be attached to the building by *wooden* stays. Iron stays are sometimes employed, and in most cases they would be safe, since electricity pursues the most direct route; but in case of an extraordinary charge, there is danger that it will divide itself, a part passing into the building through the bolt, especially if this terminates in a point. Buildings furnished with lightning rods have occasionally been struck with

How are lightning rods constructed? Materials? How are the parts fitted to each other? How terminated at bottom? How high should the rod ascend above the top of the building? How attached to the building? What is said of the kitchen chimney? How is the rod terminated at top? Have buildings furnished with lightning rods ever been struck with lightning?

lightning; but on examination it has generally, if not always, been found that the structure of the rod was defective; or that too much space was allotted for it to protect. When the foregoing rules are observed, the most entire confidence may be reposed in this method of securing safety in thunder storms.

CHAPTER VI.

PRECAUTIONS FOR SAFETY DURING THUNDER STORMS —ANIMAL ELECTRICITY—CONCLUDING REMARKS.

432. The great number of pointed objects that rise above the general level, in a large city, have the effect to dissipate the electricity of a thunder cloud, and to prevent its charge from being concentrated on any single object. Hence damage done by lightning is less frequent in a populous town, than in solitary buildings. For similar reasons, a great number of ships, lying at the docks, disarm the lightning of its power, and thus avert the injury to which the form of their masts would otherwise expose them. A solitary ship on the ocean, unprotected by conductors, would appear to be peculiarly in danger from lightning; but while the greater number of ships that traverse the ocean are wholly unprotected, accidents of this kind are comparatively rare. The reason probably is, that water being a better conductor than wood, the course of the discharge towards the water is not easily diverted, and will not take the mast in its way unless the latter lies almost directly in its course. Barns are peculiarly liable to be struck with lightning, and to be set on fire; and as this occurs at a season when they are usually filled with hay and grain, the damage is more serious, for the quantity of combustible matter they contain is such as to render the fire unmanageable.

433. Silk dresses are sometimes worn with the view of protection by means of the insulation they afford. They cannot, however, be deemed very effectual unless they completely envelop the person; for if the head and the extremities of the limbs be exposed, they will furnish so many avenues to the fluid as to render the insulation of the other parts of the system of little avail. The same remark applies to the supposed security

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What effect have a great number of high pointed objects on the liability of a place to be struck? Why is a ship at sea so seldom struck? *Why are barns so apt to be injured?* Are silk dresses a protection

that is obtained by sleeping on a feather bed. Were the person situated *within* the bed, so as to be entirely enveloped by the feathers, they would afford some protection; but if the person be extended on the surface of the bed, in the usual posture, with the head and feet nearly in contact with the bedstead, he would rather lose than gain by the non-conducting properties of the bed; since being a better conductor than the bed, the charge would pass through him in preference to that. The horizontal posture, however, is safer than the erect; and if any advantage on the whole is gained by lying in bed during a thunder storm, it probably arises from this source. The same principle suggests a reason why men or animals are so frequently struck with lightning, when they take shelter under a tree during a thunder storm. The fluid first strikes the tree, in consequence of its being an elevated and pointed object, but it deserts the tree on reaching the level of the man or animal, because the latter is a better conductor than the tree.

Tall trees, situated near a dwelling house, furnish a partial protection to the building, being both better conductors than the materials of the house, and having the advantage of superior elevation.

434. The protection of chimneys is of particular importance, for to these a discharge is frequently determined. When a fire is burning in the chimney, the vapor, smoke, and hot air, which ascend from it, furnish a conducting medium for the fluid; but even when no fire is burning, the soot that lines the interior of a chimney, is a good conductor, and facilitates the passage of the discharge.

It is quite essential, during a thunder storm, to avoid every considerable mass of water, and even the streamlets that have resulted from a recent shower; for these are all excellent conductors, and the height of a human being, when connected with them, is very likely to determine the course of an electric discharge. The partial conductors, through which the lightning directs its course, when it enters a building, are usually the appendages of the walls and partitions; the most secure situation is therefore the middle of the room, and this situation may be rendered still more secure by standing on a glass legged stool, a hair mattress, or even a thick woolen rug. The part of every

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Is a feather bed a peculiar place of safety? What posture is safest? Why are animals frequently struck under a tree? What is the influence of tall trees near a dwelling? Why is the protection of a chimney peculiarly important? Why are we to avoid collections of water? What parts of a house are safest?

building least liable to receive injury, is the middle story, as the lightning does not always pass from the clouds to the earth, but is occasionally discharged from the earth to the clouds. Hence it is absurd to take refuge in a cellar, or in the lowest story of a house; and many instances are on record in which the basement story has been the only part of the building that has sustained severe injury. Whatever situation be chosen, any approach to the fire place should be particularly avoided. An open door or window is an unsafe situation, because the lightning is apt to traverse the large timbers that compose the frame of the house, and would be determined towards the animal system on account of its being a better conductor. In a carriage the passenger is safer in the central part than next to the walls; but a carriage may be effectually protected by attaching to its upper surface metallic strips connected with the wheel tire. The fillets of silver plating which are frequently bound round the carriage, may be brought into the conducting circuit.

Animal Electricity.

435. Of the natural agencies of electricity, one of the most remarkable is that exhibited by certain species of fish, especially the *Torpedo* and *Gymnotus*. This peculiar property of the Torpedo was known to the ancient naturalists, and is accurately described by Aristotle and by Pliny. Aristotle says that this fish causes or produces a torpor upon those fishes it is about to seize, and having by that means got them into his mouth, it feeds upon them. Pliny says that this fish, if touched by a rod or spear, even at a distance paralyzes the strongest muscles.

436. The fact, however, that this extraordinary power depended upon electricity, was not known until about the year 1773, when it was ascertained by Mr. Walsh, that the Torpedo was capable of giving shocks to the animal system analogous to those of the Leyden Jar. Though this property is regarded as establishing the identity of the power with the electric fluid, yet this power, as developed in the Torpedo, has never been made to afford a spark, nor to produce the least effect upon the most delicate electrometer. As late as the year 1828, experi-

What is said of the cellar and of the fire-place,—of an open door or window? In a carriage, where is the safest place? How may a carriage be protected? *Animal Electricity.*—Were the electrical properties of the torpedo known to the ancients? What do Aristotle and Pliny say of it? When was it first known that these properties depended on electricity? Does the torpedo give sparks?

ments were made upon the Torpedo by Sir Humphry Davy, and the conclusions to which he arrived, were, that the electricity resides in this animal in a form suited exclusively to the purpose of communicating shocks to the animal system, while it has little or nothing else in common with the properties of electricity, as developed in various artificial arrangements.

The Torpedo is a flat fish, seldom twenty inches in length; but one found on the British coast was four and a half feet long. The electricity of the Torpedo has the same relation as common electricity to bodies in respect to their conducting power, being readily transmitted through metals, water, and other conductors, and not being transmitted through glass and other non-conductors.

437. The *electric organs* of the Torpedo are two in number, and placed on each side of the cranium and gills. The length of each organ is somewhat less than one third part of the length of the whole animal. Each organ consists of perpendicular columns reaching from the under to the upper surface of the body, and varying in length according to the various thickness of the flesh in different parts. The number of these columns are not constant, being not only different in different Torpedos, but likewise in different ages of the animal, new ones seeming to be produced as the animal grows. In a very large Torpedo, one electric organ has been found to consist of one thousand one hundred and eighty two columns. The diameter of a column is about one fifth of an inch. Each column is divided by horizontal partitions, consisting of transparent membrane, placed over each other at very small distances, and forming numerous interstices, which appear to contain a fluid. The number of partitions contained in a column one inch in length, has been found in some instances not less than one hundred and fifty. By this arrangement, the amount of electrified *surface* is exceedingly great; equivalent, in one instance, to one thousand and sixty four feet of coated glass. Hence, the effects of the electricity of the Torpedo are such as correspond to those which, in artificial arrangements, are produced by diffusing a given quantity of fluid over a great surface, by which its intensity is much diminished.

438. The *Gymnotus*, or Surinam eel, is found in the rivers of South America. Its ordinary length is from three to four feet; but it is said to be sometimes twenty feet long, and to

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Describe the torpedo. Describe the electric organs of the torpedo. *Describe* the columns,—the partitions.

give a shock that is instantly fatal. The electric organs of the Gymnotus, constitute more than one third part of the whole animal; they consist of two pairs, of different sizes, and placed on different sides. The shock communicated to fishes instantly paralyzes them, so that they become the prey of the Gymnotus. By irritating the animal with one hand, while the other is held at some distance in the water, a shock is received, as severe as that of the Leyden Jar.

Unlike the Torpedo, the Gymnotus gives a small but perceptible spark, affording additional proof of the identity of the power with that of electricity.

M. Humboldt, in his travels in South America, describes a singular method of catching the Gymnotus, by driving wild horses into a lake which abounds with them. The fish are wearied or exhausted by their efforts against the horses, and then taken; but such is the violence of the charge which they give, that some of the horses are drowned before they can recover from the paralyzing shocks of the eels.

The *Silurus electricus*, is a fish found in some of the rivers of Africa. Its electrical powers are inferior to those of the Torpedo and Gymnotus, but they are still sufficient to give a distinct shock to the human system.

439. Certain furred animals, particularly the cat, become spontaneously electrified. This is more especially observable on cold windy nights, when the state of the air is favorable to insulation. At such times a cat's back will frequently afford electrical sparks. Ancient historians mention a number of very remarkable occurrences, of good or evil omen, which are due to the electricity of the atmosphere. Herodotus informs us that the Thracians disarmed the sky of its thunder, by throwing their arms into the air; and that the Hyperboreans produced the same effect, by launching among the clouds darts armed with points of iron. Cæsar, in his commentaries, says, that in the African war, after a tremendous storm, which threw the whole of the Roman army into great disorder, the points of the darts of a great number of the soldiers shone with a spontaneous light. In the month of February, (says he) about the second watch of the night, there suddenly arose a great cloud, followed by a dreadful storm of hail, and in the same night the points of the darts of the fifth legion appeared on fire.

During a dry snow storm, when electricity is evolved in great

Give an account of the Gymnotus,—his electrical organs. Does the Gymnotus give sparks? What is the method of catching the Gymnotus? Give an account of the Silurus. State facts respecting the electricity of furred animals. What facts are mentioned by Herodotus and Cæsar?

quantities, and, on account of the dry state of the air, is partially insulated on conducting bodies, similar appearances are exhibited. Thus the ears of horses, and various pointed bodies, emit faint streams of light. These phenomena are sometimes exhibited in a most striking manner in a storm at sea, when the masts of a ship, yard arms, and every pointed object are tipped with lightning.

Concluding Remarks.

440. From the energy which electricity displays in our experiments, and much more in thunder storms, there can be no question that it holds an important rank among the ultimate causes of natural phenomena. Its actual agencies, however, are liable to be misinterpreted, and that they have been so in fact, is too manifest from the history of the science. After the splendid experiments with the Leyden Jar, and more especially, after the identity of electricity with lightning had been proved, electricians fancied that they had discovered the clue which would conduct them safely through the labyrinth of nature. Every thing not before satisfactorily accounted for, was now ascribed to electricity. They saw in it, not only the cause of thunder storms, but of storms in general; of rain, snow, and hail; of whirlwinds and water spouts; of meteors and the aurora borealis; and finally, of tides and comets and the motions of the heavenly bodies. Later electricians have found in the same agent the main spring of animal and vegetable life, and the grand catholicon which cures all diseases. Recent attempts have been made to establish the very identity of galvanic electricity and the nervous influence, by which the most important functions of animal life are controlled.

Among the most important of the agencies of electricity in the economy of nature, is that which, according to the views of Sir Humphry Davy, it sustains in relation to the chemical agencies of bodies. Chemical and electrical attraction, he supposes, are one and the same thing, or at least dependent on the same cause, the attraction between the elements of a compound arising solely from their being naturally in opposite electrical states. But the discussion of this hypothesis belongs more appropriately to Galvanism, a branch of our subject which, on account of its peculiarities, especially in the mode of excitation, has been constituted a separate department of science.

Does electricity attend snow storms? What rank does electricity hold among the causes of natural phenomena? Have its actual agencies been overrated? What different effects have been ascribed to it? What are Sir Humphry Davy's views respecting the identity of chemical and electrical attractions?

PART V.—MAGNETISM.

GENERAL PRINCIPLES.

441. MAGNETISM *is the science which treats of the properties and effects of the magnet.*—The same term is also used to denote the unknown cause of magnetic phenomena; as when we speak of magnetism as excited, imparted, and so on.

Magnets are bodies, either natural or artificial, which have the power of attracting iron, and the power, when freely suspended, of taking a direction towards the poles of the earth.

The natural magnet is sometimes called the *loadstone.** It is an oxide of iron of a peculiar character, found occasionally in beds of iron ore. Though commonly met with in irregular masses only a few inches in diameter, yet it is sometimes found of a much larger size. One recently brought from Moscow to London weighed one hundred and twenty five pounds, and supported more than two hundred pounds of iron.

442. The *attractive* powers of the loadstone have been known from a high antiquity, and are mentioned by Homer, Pythagoras, and Aristotle. But the *directive* powers were not known in Europe until the thirteenth century, when they were discovered by a Neapolitan named Flavio; though some writers have endeavored to trace the history of the compass needle to a remoter period, and some have strenuously maintained that the Chinese were in possession of it many centuries before it was known to Europeans.

Magnetism is the most recent of all the physical sciences, and notwithstanding the numerous discoveries achieved in it within a few years, and the remarkable precision with which its laws have been ascertained, yet it is still to be regarded as a science quite in its infancy, although it is rapidly progressive.

443. If a magnet be rolled in iron filings, it will attract them to itself. This effect takes place especially at two opposite

Magnetism.—Define magnetism and magnets. What is the loadstone? Which of its powers were known to antiquity? When were the directive powers discovered? What is the present state of this science? What is the effect when a magnetic bar is rolled in iron filings?

* *Said to be derived from lædan*, a Saxon word which signifies to guide.

points, where a much greater quantity of the filings will be collected than in any other part of the body. The two opposite points in a magnet, where its attractive powers appear chiefly to reside, are called its poles. The straight line which joins the poles, is called the axis.

Fig. 92.

If a large sewing needle or small bar of steel be rubbed on the loadstone, one extremity on one pole, and the other extremity on the other, the needle or bar will itself become a magnet, capable of exhibiting all the properties of the loadstone. Without stopping at present to describe more minutely the process of making artificial magnets, we will suppose ourselves provided with several magnetic needles and bars, and we may proceed with them to study the leading facts of the science of magnetism. By attaching a fine thread to the middle of a needle, and suspending it so as to move freely in a horizontal plane; or by resting it on a point, as is represented in Fig. 93, we shall have a simple and convenient apparatus for numerous experiments. The needle thus suspended will place itself in a direction nearly, though not exactly, north and south. If the needle is drawn out of the position it assumes when at rest, it will vibrate on either side of that position until it finally settles in the same line as before, one pole always turning to the north, and the other towards the south. Hence the two poles are denominated respectively *north and south poles.* In magnets prepared for experiments, these poles are marked either by the letter N and S, or by a line drawn across the magnet near one end, which denotes that the adjacent pole is the north pole.

Fig. 93.

444. By means of the foregoing apparatus we may ascertain that the magnet has the following general properties, viz:

First, powers of attraction and repulsion.

Secondly, the power of communicating magnetism to iron or steel by induction.

Thirdly, polarity, or the power of taking a direction towards the poles of the earth.

Fourthly, the power of inclining itself towards a point below the horizon, usually denominated the *dip of the needle.*

Define the poles and axis of a magnet. How may a steel needle be made a magnet? How may we suspend a needle for experiments? State the *four* leading properties of the magnet.

The farther development of these properties will constitute the subject of the following chapters.

CHAPTER I.

OF MAGNETIC ATTRACTION.

445. *When either pole of a magnet is brought near to a piece of iron, a mutual attraction takes place between them.*

Thus, when the ends of a magnetic bar or needle are dipped into a mass of iron filings, these adhere in a cluster to either pole. A bar of soft iron, or a piece of iron wire, resting on a cork, and floating on the surface of water or quicksilver, may be led in any direction by bringing near to it one of the poles of a magnet. This action is moreover *reciprocal*, that is, the iron attracts the magnet with the same force that the magnet attracts the iron. If the two bodies be placed on separate corks and floated, they will approach each other with equal momenta; or if the iron be held fast, the magnet will move towards it.

446. Two other metals besides iron, namely, nickel and cobalt, are susceptible of magnetic attraction. These metals, however, exist in nature only in comparatively small quantities, and therefore by magnetic bodies, are usually intended such as are ferruginous. Even iron, in some of its combinations with other bodies, loses its magnetic properties; only a few of the numerous ores of iron are attracted by the magnet. But soft metallic iron, and some of the ores of the same metal, affect the needle even when existing in exceedingly small quantities, so that the magnet becomes a very delicate test of the presence of iron. Compass needles are sometimes said to be disturbed by the minute particles of steel left in the dial plate by the graver; and the proportion of iron in some minerals may be exactly estimated by the power they exert upon the needle.

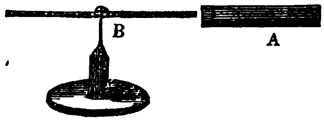
447. *In the action of magnets on each other, poles of the same name repel, those of different names attract each other.*

Magnetic Attraction.—What takes place when either pole of a magnet is brought near to a piece of iron? Is the action reciprocal? What metals besides iron are susceptible of magnetic attraction? What minute portions of iron may be detected by the magnetic needle? What poles repel and what attract each other?

Thus, the north pole of one magnet will repel the north pole of the other, and attract its south pole. The south pole of one will repel the south pole of the other and attract its north pole. These effects, it will be perceived, are analogous to those produced by the two species of electricity; and they equally imply two species of magnetism or two magnetic fluids, (as is convenient to call them) namely, the northern and the southern; or, as they are now denominated, the *boreal* and the *austral* fluids.

448. *By bringing a magnet near to iron or steel, the latter is rendered magnetic by Induction.*

Fig. 94.



Thus, let the north pole of a magnetic bar A, (Fig. 94.) be brought near to one end of an unmagnetized bar of soft iron B: the iron will immediately become itself a magnet, capable of attracting iron filings, having polarity when suspended, and possessing the power of communicating the same properties to other pieces of iron. It is, however, only while the iron remains in the vicinity of the magnet, that it is endued with these properties; for let the magnet be withdrawn and it loses at once all the foregoing powers. This, it will be remarked, is asserted of *soft iron;* for steel and hardened iron are differently affected by induced magnetism.

On examining the kind of magnetism induced upon the two ends of the iron bar B, (Fig. 94.) which we may easily do by bringing near it the poles of the needle, (Fig. 93.) we shall find that the nearer end has south, and the remoter end north polarity. This effect also is analogous to that produced by electrical induction. A corresponding effect would have taken place, had the south instead of the north pole of the magnet been presented to the bar of iron; in which case the nearer end would have exhibited northern, and the remoter end southern polarity. Or, to express this important proposition in general terms,

Each pole of a magnet induces the opposite kind of polarity in that end of the iron which is nearest to it, and the same kind in that end which is most remote.

What names are given to the two kinds of magnetism? Explain how iron or steel is rendered magnetic by *induction*. What kind of electricity is induced on the end nearest to the magnet and on the end most remote?

449. *The power of a magnet is increased by the exertion of its inductive power upon a piece of iron in its neighborhood.*

The end of the piece of iron contigious to the pole of the magnet, is no sooner endued with the opposite polarity, than it re-acts upon the magnet and increases its intensity, and a series of actions and re-actions take place between the two bodies, similar to what occurs in electrical induction. On this account the powers of a magnet are increased by action, and impaired or even lost by long disuse. By adding, from time to time, small pieces of iron to the weight taken up by a magnet, its powers may be augmented greatly beyond their original amount. Hence, the force of attraction of the dissimilar poles of two magnets, is greater than the force of repulsion of the similar poles; because, when the poles are unlike, each contributes to enhance the power of the other, but when they are alike, the influence which they reciprocally exert, tends to make them unlike, and of course to impair their repulsive energies.

Hence, also, a strong magnet has the power of reversing the poles of a weak one. Suppose the north pole of the weaker body to be brought in contact with the north pole of the stronger; the latter will expel north polarity, or the boreal fluid, and attract the austral, a change which in certain cases will be permanent.

If the north pole of a magnetic bar be placed upon the middle of an iron bar, the two ends of the latter will each have north polarity, while the part of the bar immediately in contact with the magnet receives south polarity; and if the same north pole be placed on the center of a circular piece of iron, all parts of the circumference will be endued with north polarity while the plate will have a south pole in the center. By cutting the plate into the form of a star, each extremity of the radii becomes a weak north pole when the north pole of a magnet is placed in the center of the star. If an iron bar is placed between the dissimilar poles of two magnetic bars, both of the magnets will conspire to increase the intensity of each pole of the bar, and the magnetism imparted to the bar will be considerably stronger than from either magnet alone; but if the same bar be placed between the two similar poles, the opposite polarity will be imparted to each end, while the same polarity is given to the center of the

How is the power of a magnet influenced by the exertion of the inductive power? How are the powers of a magnet affected by use and by disuse? What effect has a strong magnet on the poles of a weak one? What is the effect when the north pole of a magnet is placed upon the middle of an iron bar? Also when placed in the center of a star? When the iron bar is *placed between two dissimilar* poles of two magnetic bars?

bar. Thus, if the bar be placed between the north poles of two magnets, each end of the bar will become a south pole and the center a north pole. When one end of a magnetic bar is applied to the ends of two or more wires or sewing needles, the latter arrange themselves in radii diverging from the magnetic pole. This effect is in consequence of their remoter ends becoming endued with similar polarity, and repelling each other. A like effect is observable among the filaments of iron filings that form a tuft on the end of a magnetic bar.

450. The foregoing experiments are sufficient to show that when a piece of iron is attracted by the magnet, it is first itself converted into a magnet by the inductive influence of the magnetizing body. Each of the iron filings which compose the tuft at the pole of a magnetic bar or needle, is itself a magnet, and in consequence of being such, induces the same property in the next particle of iron, and that in the next, and so on to the last. Hence magnetic attraction does not exist, strictly speaking, between a magnet and iron, but only between the opposite poles of magnets; for the iron must first become a magnet before it is capable of magnetic influence.

451. *Soft iron readily acquires magnetism and as readily loses it; hardened steel acquires it more slowly, but retains it permanently.*

In the preceeding examples, the magnetism acquired by a bar of iron, by the process of induction, is retained only so long as the magnetizing body acts upon it. Soon after the two bodies are separated the bar loses all magnetic properties.

When a bar of steel is placed very near a strong magnet, the action of the magnet commences immediately upon the end of the bar nearest to it, the north pole, for example, communicating south polarity to the contiguous extremity of the bar. According to our previous experience, we should expect to find the remote end of the bar a north pole; but such is not the *immediate* result; a sensible time is required before the north polarity is fully imparted to the remote extremity. Indeed, if the bar be a long one, it sometimes happens that the northern polarity never reaches the farthest end, but stops short of it at some intermediate point. This north pole is succeeded by a second south

How do sewing needles arrange themselves around the pole of a magnet? How do iron filings thus arrange themselves? What change is wrought in each filing? Does magnetic attraction exist between the needle and unmagnetized iron? State the respective powers of soft iron and hard steel to receive magnetism.

pole, that by another north pole, and thus several alternations between the two poles occur before reaching the end of the bar.

452. The process of magnetizing a steel bar or needle is accelerated by any cause which excites a tremulous or vibratory motion among the particles of the steel. Striking on the bar with a hammer promotes the process in a remarkable degree, especially if it occasions a ringing sound, which indicates that the particles are thrown into a vibratory motion. The passage of an electric discharge through a steel bar under the influence of a magnet, produces permanent magnetism. Heat also greatly facilitates the introduction of the magnetic fluid into steel. The greatest possible degree of magnetism that can be imparted to a steel bar is communicated by first heating the steel to redness, and while it is under the influence of a strong magnet, quenching it suddenly in cold water.

A magnet, however, loses its virtues by the same means as, during the process of induction, were used to promote their acquisition. Accordingly, any mechanical concussion, or rough usage, impairs or destroys the powers of a magnet. By falling on a hard floor, or by being struck with a hammer, it is greatly injured. Heat produces a similar effect. A boiling heat weakens, and a red heat totally destroys the power of a needle. On the other hand, cold augments the power of the magnet; indeed magnets improve with every reduction of temperature hitherto applied to them.

453. *If a steel bar, rendered magnetic by induction, be divided into any two parts, each part will be a complete magnet, having two opposite poles.*

We here meet with a remarkable distinction between magnetic and electrical induction. When a body, electrified by induction, is divided into two equal parts, the individual electricities alone remain in each part respectively; but in the case of magnetic induction, although no appearance of polarity be exhibited except at the two ends, yet wherever a fracture is made, the two ends separated by the fracture immediately exhibit opposite polarities, each being of an opposite name to that of the original pole at the other end of the fragment. If each of the two fragments be again divided into any number of parts, each of these parts is a magnet perfect in itself, having two opposite poles.

By what means is the process of magnetizing a steel bar accelerated? What effect has the passage of an electric discharge through a steel bar? What *is the effect of heat?* By what means does the magnet lose its *virtues? Show the difference* between magnetic and electric induction.

In magnetism, therefore, there is never, as in electricity, any *transfer* of properties, but only the excitation of such as were already inherent in the body acted upon. Magnetism never passes out of one body into another; nor can we ever obtain a piece of iron or steel that contains exclusively either northern or southern polarity.

454. *The force of attraction, or of repulsion, exerted upon each other by the poles of two magnets, placed at different distances, varies inversely as the square of the distance.*

This law was ascertained by means of a very delicate apparatus, in a manner similar to that adopted in investigating the law of electrical attraction. The same law, therefore, which governs the attraction of gravitation, likewise controls electrical and magnetic attractions. It is the most extensive law of the physical world. Nor is this action at a distance prevented, or even impaired, by the interposition of other bodies not themselves magnetic.

455. *The magnetic power of iron resides wholly on its* SURFACE, *and is independent of the mass.*

Thus, a hollow globe of iron of a given surface, will have the same effect on the needle as though it were solid throughout. In this fact we again meet with a striking analogy between magnetism and electricity, the same property having before been shown to belong to the electric fluid. This is one of the most recent discoveries in magnetism, and was made by Professor Barlow of the Military Academy at Woolwich, (Eng.) to whose ingenious and assiduous labors are due many of the latest and most important investigations in this science.

CHAPTER II.

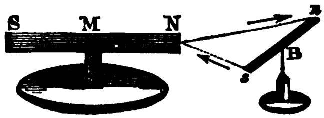
OF THE DIRECTIVE PROPERTIES OF THE MAGNET.

456. *If a small needle be placed near one of the poles of a magnet, with its center in the axis of the magnet, it will take a direction in a line with that axis.*

Is there in magnetism any *transfer* of properties? How is the force of attraction at different distances from a magnet? How was the law *ascertained*? In what part of a body does magnetic attraction reside?

Directive properties.—If a small needle, suspended so as to move freely, *be placed* near the pole of a magnet, what direction will it take?

Fig. 95.



Thus, let S N be a large magnetic bar, and *s n* a small needle placed near the north pole of the magnet with its center in the axis: it will be seen that the action of the pole of the magnet is such as to bring the neeedle into a line with the magnet. The action of the bar upon the needle, tending to give it this direction, is equal to the sum of its actions upon both poles ; while the attraction of the bar upon the whole needle, being only that which the attraction for *s*, on account of its nearness, exceeds the repulsion of *n*, must be less than the directive force.

457. *If the needle be placed at right angles to the bar, with one of its poles directed towards the center of the bar, it will take a direction parallel to the bar.*

By supposing B (Fig. 95.) to be placed as indicated in the above proposition, it will be seen, that the actions of both poles of the magnet would conspire in relation to each pole of the needle, and that these forces can be in equilibrium only when the needle is parallel with the bar. The needle in this situation has a tendency to move towards the magnet, because the attractions being exerted on the nearer and the repulsions on the remoter poles, the sum of the attractions exceeds that of the repulsions.

458. *Iron filings or other ferruginous bodies, which are free to obey the action of a magnetic bar, naturally arrange themselves, in curve lines, from one pole of the magnet to the other.*

Fig. 96.

Thus, if we place a sheet of white paper on a magnetic bar, laid on the table, and sprinkle iron filings on the paper, the filings will arrange themselves in curves around the poles of the magnet.

If a needle be placed at *right angles* to a magnetic bar, what direction will it take? How do iron filings arrange themselves around a magnetic bar?

459. *The magnetic needle, when freely suspended, seldom points directly to the pole of the earth, but its deviation from that pole is called the* DECLINATION, *or the* VARIATION *of the needle.*

A vertical circle drawn through the line in which the needle naturally places itself, is called the *magnetic meridian*. A plane passing at right angles to the magnetic meridian, through the center of the needle, is called its *magnetic equator*. A line drawn on the surface of the earth passing through the place where the needle points directly to the north pole, and where of course the geographical and magnetic meridians coincide, is called the *line of no variation.*

The *North Magnetic Pole* was discovered by Commander James Ross, of the British Navy, in 1832. It is situated in the region lying north of Hudson's and west of Baffins's Bay, in Latitude 70° N. Longitude 96° 30′ W.

The *line of no variation* encompasses the globe, but is subject to numerous irregularities. Setting out at the magnetic pole, we may trace it in a direction a little east of south through the British Possessions until it crosses Lake Ontario, the western part of the state of New York, the central part of the State of Pennsylvania, passing a little eastward of Washington City. Thence it pursues a southeasterly course towards the South Polar Regions. Places lying westward of this line have, within certain limits, easterly, and those lying eastward, westerly directions. Throughout the greater part of the western hemisphere the variation is eastward.

The declination of the needle is not constant, but is subject to a small annual change, which carries it to a certain limit on one side of the pole of the earth, when it becomes stationary for a time, and then returns to the pole and proceeds to a certain limit on the other side of it, occupying a period of many years during each vibration.

In the United States, the variation of the needle in different places is as follows:—

New Haven,	in 1835,	5° 52′	West.
New York City,	1834,	4° 25′	do.
Albany,	1834,	6° 40′	do.
Burlington, Vt.	1834,	8° 50′	do.

Define or explain what is meant by the *declination* of the needle,—also by the magnetic meridian, and magnetic equator? What is the position of the North Magnetic Pole,—Its Latitude and Longitude? Trace the line of no variation. What is the variation of places lying westward and eastward of this line respectively? State the amount of the variations at New Haven, New York City, Albany and Burlington.

The annual variation is 2′ 49″, by which quantity the needle approaches the pole.

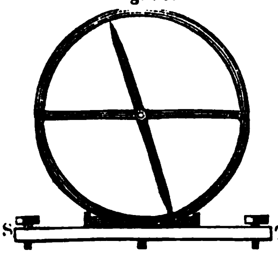
The variation of the needle is not, therefore, the same at the same time, in all parts of the earth, but every place has its particular declination. For instance, if we sail from the Straits of Gibraltar to the West Indies, in proportion as we recede from Europe and approach America, the compass will point nearer and nearer due north; and when we reach a certain part of the Gulf of Mexico, it will point exactly north. But if we sail from Great Britain to the southern coast of Greenland, we shall find the needle deviate farther and farther from the north, as we approach Greenland, where the deviation will not be less than 50°. In some parts of Baffin's Bay the needle points nearly due west.

460. *Beside the annual variation, the magnetic needle is subject to daily changes called the* DIURNAL VARIATION.

The deviation of the horizontal needle from its mean position is easterly in the morning, and arrives at its maximum about eight o'clock. Thence it returns rapidly to its mean position which it reaches between nine and ten o'clock, and then its variation becomes westerly, at first increasing rapidly, so as to reach its maximum at about one o'clock in the afternoon, and then slowly receding during the rest of the day, and arriving at its mean position about ten o'clock at night.

461. *A needle first balanced horizontally on its center of gravity, and then magnetized, no longer retains its level, but its north pole spontaneously takes a direction to a point below the horizon called the* DIP OF THE NEEDLE.

Fig. 97.



The *Dipping Needle*, is represented in Fig. 97. When used, it is to be placed in the magnetic meridian, and the stand which supports it, made perfectly level, by means of the adjusting screws attached.

What is the average annual variation? What changes of declination do we meet with in going from the Straits of Gibraltar to the West Indies, or from Great Britain to the southern coast of Greenland? How does the needle point in some parts of Baffin's Bay? State the facts respecting the *Diurnal Variation* of the needle. Also respecting the Dip.

The dip of the needle is very different in different parts of the globe, being, in general, least in the equatorial and greatest in the polar regions. At certain places on the globe the needle has no dip, that is, becomes perfectly horizontal, and a line uniting all such places is called the *magnetic equator of the earth.* Again, in the Polar Regions, the dipping needle sometimes becomes nearly perpendicular to the horizon. In the middle latitudes, the dip is greater or less, but does not correspond exactly to the latitudes.

462. *The force exerted by the magnetism of the earth varies in different places: its comparative estimate for any given place, is called the* MAGNETIC INTENSITY *for that place.*

As in the case of the pendulum in its relation to the force of gravity, the magnetic intensity may be measured by the *number of oscillations*, which a needle drawn a given number of degrees from its point of rest, performs in a certain time, as a minute for example, the force being as the square of the number of oscillations. In general it is well ascertained that the magnetic intensity is least in the equatorial regions, and increases as we advance towards the poles. It is probably at its maximum at the magnetic poles. By ascertaining from actual observation, a number of different places on the surface of the earth where the magnetic intensities are equal, and connecting them by a line, it appears that they arrange themselves in a curve around the magnetic pole. These lines are called *isodynamic curves.* Extensive journies have been undertaken by Humboldt, Sabine, Hansteen, and others, to ascertain the point on the surface of the earth where the magnetic intensities are equal, for the purpose of describing these curves. The earliest results indicated the position of the magnetic pole to be in the north-eastern part of Hudson's Bay; but the directions of these curves presented such anomalies as to suggest the idea of a second magnetic pole in the opposite hemisphere. With a view of ascertaining this point, Professor Hansteen, of Christiana, several years since undertook a journey into Siberia, at the expense of the king of Sweden, and has fully confirmed the fact, that there exists a second magnetic pole to the north of Siberia, around which the isodynamic curves arrange themselves in reg-

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Where is the Dip least, and where greatest? What is the earth's magnetic equator? How is the dipping needle inclined in the Polar Regions? Define *Magnetic Intensity.* How may it be measured? In what parts of the earth is the magnetic intensity least? Where greatest? Explain the isodynamic curves. Where is the second magnetic pole situated?

ular order. From experiments made in deep mines, and in the upper regions of the atmosphere by aeronauts, it appears that in both these situations, the magnetic intensity is the same as at the corresponding places on the surface of the earth.

463. *The effects produced by the earth on a magnetic needle, correspond to those produced on it by a powerful magnet, and hence the earth itself may be considered as such a magnet.*

The magnetism of the earth has been supposed by some, to result from a great magnet lying in the central parts of the earth; by others, to be nothing more than the *resultant* of all the smaller magnetic forces scattered through various parts of the terrestial sphere; and by others to be excited on the surface of the earth by the action of the solar rays.

The supposition of a great magnet in the interior of the earth, to which all the phenomena of terrestial magnetism are to be ascribed, is the earliest hypothesis, and is adequate to explain most of the facts of the science. But such a supposition is inconsistent with the recent discovery of two north poles, implying the existence of four magnetic poles of the earth. The opinion of Biot, that terrestial magnetism is only the aggregate or resultant of all the individual magnetic forces residing in different parts of the earth, appears to be no improbable supposition, and accords well with the general doctrine of the composition of forces.

464. In the year 1813, Dr. Morichini, of Rome, announced that the violet rays of the solar spectrum have the propetry of rendering iron magnetic. In 1825, these experiment were repeated and extended by Mrs. Sommerville, and resulted in proving that the magnetizing power is not confined to the violet rays, but extends to the indigo, blue, and green rays. The probable conclusion is, that a class of rays emanate from the sun which have the property of producing magnetism, and are distinct from those which afford light and heat, and produce chemical changes. Hence, in the solar beam there are at least four distinct kinds of rays, denominated, respectively, *colorific*, *calorific*, *chemical*, *and magnetizing* rays.

465. *Electricity and magnetism are, in some of their properties, remarkably alike, but in others strikingly dissimilar.*

How is the magnetic intensity of deep mines, and the upper regions of the atmosphere? What is said of the magnetism of the earth? How is it supposed to be produced? How does the supposition that the earth is a magnet accord with the existence of four magnetic poles? What is Biot's opinion? What is said of solar magnetic rays?

Several of these analogies have been already incidentally mentioned; but it will be useful to the student to consider them in connexion. Electricity and magnetism agree in the following particulars: (1.) Each consists of two species, the vitreous and resinous electricities, and the austral and boeral magnetisms. (2.) In both cases, those of the same name repel, and those of opposite names attract each other. (3.) The laws of induction in both are very analogous. (4.) The force, in each, varies inversely as the square of the distance. (5.) The power, in both cases, resides at the surface of bodies, and is independent of their mass.

But electricity and magnetism are as remarkably unlike in the following particulars. (1.) Electricity is capable of being excited in all bodies and of being imparted to all: magnetism resides almost exclusively in iron in its different forms, and, with a few exceptions, cannot be excited in any other than ferruginous bodies. (2.) Electricity may be *transferred* from one body to another; magnetism is incapable of such transference; magnets communicate their properties merely by *induction*, a process in which no portion of the fluid is withdrawn from the magnetizing body. (3.) When a body of elongated figure is electrified by induction, on being divided near the middle, the two parts possess, respectively, the kind of electricity only which each had before the separation; but when a bar of steel or a needle magnetized by induction, is broken into any number of parts, each part has both polarities and becomes a perfect magnet. (4.) The directive properties and the various consequences that result from it, the declination, annual and diurnal variations, the dip, and the different intensities in different parts of the earth, are all peculiar to the magnet and do not appertain to electrified bodies.

Methods of making Artificial Magnets.

466. If the learner has made himself acquainted with the principles expounded in the preceding propositions, he will be qualified to proceed, with interest and intelligence, to an explanation of the leading methods practised in the manufacture of artificial magnets. These methods also, by involving a practical application of those principles, will serve to impress them on the memory and to render the knowledge of them familiar.

State the analogies between electricity and magnetism,—also the differences. *Method of making Magnets.*—State the leading principles to be kept in view in making artificial magnets.

It will be recollected that magnets are made from other magnets; that this is done, not by any *transference* of a portion of the power of the magnetizing body, but by the development of the powers naturally residing in the body to be magnetized; that this development is effected wholly on the principle of induction; that the original magnet gains instead of losing by its action on other bodies; that this power may be induced on iron by the agency of an artificial magnet, or of the loadstone, or of the earth, which is itself a weak magnet, and acts upon the same principles as any other magnet. It must also be kept clearly in mind, that soft iron or steel readily acquires, and as readily loses the magnetism induced upon it, and that hardened iron or steel receives it slowly and with much difficulty, but retains it permanently. As the earth itself may be supposed to have been the original source of magnetism in all other bodies in which it is found, there are methods of magnetizing from the earth without the aid of either the loadstone or an artificial magnet.

467. *A needle may be magnetized by simply suffering it to remain in contact with the pole of a strong magnet; or better between the opposite poles of two magnets.*

The effect produced by two magnets is much more than double that of one magnet, as may be inferred from Art. 448. But if the needle be of considerable length, several intermediate sets of poles are sometimes developed, as will be seen by applying iron filings. It adds much to the power of the two magnetic bars between which the needle is placed, if to each extremity of the bar most remote from the needle, a mass of soft iron is placed. The iron in this case, acts and re-acts by induction; and hence, whenever magnets are not in use, they require to be connected with iron to prevent the loss of their powers. Pieces of soft iron thus connected with magnets, for the purpose of augmenting their power by induction, are called *armatures*. Thus A is the armature of the horse shoe magnet represented in Fig. 99.

468. But it must be recollected that the two species of magnetism are not, like those of electricity, separated to a distance from each other, so that one kind may be wholly collected at one end of the bar and the other kind at the other end; but that the two are separated only at a minute distance, remaining in the

What is the simplest way of magnetizing a needle? How does the effect produced by two magnets compare with that of one? What is said of intermediate sets of poles? What is the effect of placing a mass of soft iron near to the remote extremity of the bar? Define armatures.

immediate vicinity of each other throughout the whole length of the bar. Hence, in order to give the magnetizing pole its full effect, it becomes necessary to apply it successively to every part of the bar, from one end to the other.

A more effectual method of magnetizing a needle is the following: Place two magnetizing bars, A, B, parallel to each other, with their dissimilar poles adjacent; unite the poles at one end by a piece of soft iron R, and apply the poles at the other end to the needle, as is represented in Fig. 98. Upon this principle, that is, the increased energy with which the two poles act together, is formed what is called the horse shoe magnet, which derives its name from its peculiar figure, (Fig. 99.) Bars of this form are converted into magnets upon the same principles as straight bars, the magnetizing bar being made to follow the curvature always in the same direction. A very efficacious mode of making horse shoe magnets is thus described by Professor Barlow. Two horse shoe bars may be united at their ends, in such a manner that the poles which are to be of opposite names shall be in contact. They are then to be rubbed with another strong horse shoe magnet, placing the latter so that its north pole is next to the south pole of one of the new magnets, and consequently its south pole next to the north pole of the same; carrying the movable magnet round and round, always in the same direction. This is esteemed one of the most eligible modes of making powerful magnets.

Fig. 98.

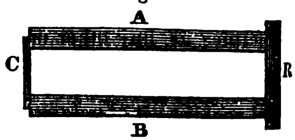
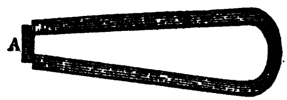


Fig. 99.



The horse shoe magnet is itself very convenient for imparting magnetism to other bodies. Place the poles near the center of the needle; move them along its surface backwards and forwards, taking care to pass over each half of it an equal number of times; repeat the same operation on the other side; and the needle will become speedily and effectually magnetized.

469. The best mode of making magnetic needles in general, is expressed in the following rule, given, as the result of very extensive and accurate experiments, by Capt. Kater.

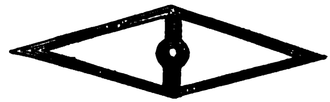
Why is it necessary to apply the magnetizing pole to all parts successively? Describe the horse shoe magnet. What is Barlow's method of making them? How to magnetize needles with the horse shoe magnet?

Place the needle in the magnetic meridian; join the opposite poles of a pair of bar magnets, (the magnets being in the same line) and lay the magnets so joined, flat upon the needle, with their poles upon its center; then having elevated the distant extremities of the magnets, so that they may form an angle of about two or three degrees with the needle, draw them from the center of the needle to the extremities, carefully preserving the same inclination; and having joined the poles of the magnets at a distance from the needle, repeat the operation ten or twelve times on each surface.

The Compass.

470. The Compass, (the importance of which to mankind, has attached to the subject of magnetism its principal value,) is of many different forms, but the chief varieties are the Land compass, the Mariner's compass, the Azimuth compass, and the Variation compass. The needle, in all these varieties, is usually a thin flat plate of steel, tapering at the extremities; but, a more eligible form has been proposed by Capt. Kater, consisting of four narrow strips of steel, united in the form of a hollow rhombus, (Fig. 100.) It is found advantageous to concentrate the powers of the needle as much as possible in the two extremities, and to avoid all inequalities, arising from intermediate poles, or from a difference of strength in different parts. The needle is secured at the point of suspension, and furnished with a conical cap of brass which rests on a perpendicular pin; and still farther to diminish friction, the point which rests on the extremity of the pin, is made of agate, one of the hardest mineral substances. Since, if the needle is magnetized after having been balanced on its center of gravity, it would no longer remain horizontal, the equipoise is restored by attaching a small weight to the elevated side.

Fig. 100.



471. The compass, in its simplest form, consists of a needle like the foregoing, enclosed in a suitable box covered with glass. This is all that is essential when it is required merely to know the direction of the meridian, or the north and south points. But, for most purposes, the compass is furnished with a graduated circular card, divided into degrees and minutes; and in the mariner's compass the card is also divided into thirty-two

State Kater's mode of making magnetic needles. The Compass.—*Describe the different forms of needles?* What is essential to the compass? *How is the card graduated?*

equal parts called rhumbs. The card thus divided is fastened to the needle itself, and turns with it.

472. Thin, slender needles have the greatest directive powers, and are most sensible, since they undergo less friction than those which are heavier; but due regard to strength requires them to be made of a certain degree of thickness; an increase of length is attended with an increase of directive power; but when the thickness remains the same, the weight, and consequently the friction, increases in the same ratio; no advantage, therefore, as to directive power, can be obtained by any increase of length. Moreover, needles which exceed a very moderate length, are liable to have several sets of poles, a circumstance which is attended with a great diminution of directive force. On this account, short needles, made exceedingly hard, are generally preferable.

Fig. 101.

473. The great imporance of the mariner's compass, has made its construction an object of much attention, and the best *artists* have tried their skill upon it. The compass is suspended

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What kind of needles have the greatest directive power? Which are best, long or short needles?

in its box in such a manner as to remain in a horizontal position, notwithstanding all the motions of the ship. This is effected by means of *gimbals*. This contrivance consists of a hoop, usually of brass, (Fig. 101.) fastened horizontally to the box by two pivots placed opposite to each other, and constituting the axis on which the hoop turns up and down. At an equal distance from the pivots on each side, that is, at the distance of 90° from each pivot, two other pivots are attached to the ring at right angles to the former, on which the inner box that contains the card is hung. Of course, when it turns on these pivots, its motion is at right angles with that of the hoop. Therefore, all the motions of which the compass box is capable, are performed around two axes which intersect each other at right angles; consequently, the point of intersection, being in both axes, will not move at all. But the needle and the attached card rests upon this point, and are connected with the compass box in no other point. Hence they remain constantly horizontal in every position of the box.

The Azimuth compass* differs from the common mariner's compass only in having sights attached, by which the bearing of any object with the meridian may be ascertained. The Surveyor's compass is a variety of the Azimuth compass.

Describe the Mariner's compass. By what means is the needle kept in a horizontal position? How is the Azimuth compass constructed?

* *Azimuth*, as applied to a star or any celestial object, is an arc of the horizon intercepted between the meridian and a vertical circle passing through the object.

PART VI.—OPTICS.

PRELIMINARY DEFINITIONS AND OBSERVATIONS.

474. Optics *is that branch of Natural Philosophy which treats of Light and Vision.*

More particularly, it is the object of this science to investigate the *nature* of the agent on which the phenomena of vision depend; to treat of the *motions* of light, in respect to its direction, its velocity, and its reflexion from the surfaces of bodies; to trace its change of direction, and the various other modifications it undergoes by passing through different transparent media; to explain the *phenomena of nature* which depend upon the properties of light, embracing the doctrine of *color;* to trace the relation between light and the structure of the eye, comprehending the subject of *vision;* and finally, to describe the various *instruments* to which a knowledge of the principles of Optics has given birth, disclosing many new and wonderful properties of light, and extending the range of human vision, on the one hand, to myriads of objects too minute, and on the other, to numberless worlds too remote, to be seen by the unassisted eye.

475. Luminous bodies are naturally of two kinds, such as shine by their own light, as a lamp or the sun, and such as shine by borrowed light, as the moon, and most of the visible objects in nature.

A *ray* is a line of light; or it is the line which may be conceived to be described by a particle of light. In a more general sense, the term is applied to denote the smallest portion of light which can be separately subjected to experiment. A *beam* is a collection of parallel rays. A *pencil* is a collection of converging or diverging rays. A *medium* is any space through which light passes. When a space is a perfect void, so as to offer no obstruction to the passage of light, it is said to be a *free medium;* when the space intercepts a portion only of the light, it constitutes a *transparent medium.* Transparency, however,

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Optics.—Define Optics. Enumerate more particularly the objects of this science in regard to the nature and motion of light, to color, to vision, and to optical instruments? How are luminous bodies divided into two kinds? Define a ray, a beam, a pencil, a medium, a free medium, a transparent medium.

may exist in different degrees. When the medium itself is invisible, as portions of air, it is said to be *perfectly* transparent; when the medium is visible, but objects are seen distinctly through it, as in the clearest specimens of glass and crystals, it is said to be, simply, *transparent;* when objects are indistinctly seen through it, it is *semi-transparent;* and when a mere glimmering of light passes through, without representing the figure of objects, it is *translucent.* Bodies that transmit no light are said to be *opake.*

476. *Rays of light, while they continue in the same uniform medium, proceed in straight lines.*

For objects cannot be seen through bent tubes; the shadows of bodies are terminated by straight lines; and all the conclusions drawn from this supposition, are found by experience to be true. If two bodies with plane surfaces, as two disks of metal, be held between the eye and some luminous point, as a star, on bringing the two planes gradually towards each other, the star may be seen through the intervening space until the planes come completely into contact; but if one of the surfaces is convex and the other concave, the light is intercepted before the surfaces have met. In consequence of the rectilinear motion of light, it forms angles, triangles, cylinders, cones, &c., and thus its affections fall within the province of geometry, the principles of which are applied with great effect to the development of the properties and laws of light, after a few fundamental properties are established by experiment. From every point in a luminous object, an inconceivable number of rays of light emanate in every direction, when not prevented by obstacles that intercept it. Thus, from every point in the flame of a candle, as seen by night, light diffuses itself, pervading an immense sphere, and filling every part of the space so perfectly, that not the minutest point can be found destitute of some portion of its rays. Any luminous body of this kind is called a *radiant.* The pencil of light which proceeds from a radiant, is a cone, the sections of which, made by any plane, correspond to the figures called conic sections, If any portion of the pencil be intercepted by a rectilateral figure, that portion constitutes a pyramid of which the figure is the base and the luminous point itself is the vertex.

When is a body said to be perfectly transparent, transparent, semi-transparent, translucent, or opake? What is the direction of rays of light? State the proofs that it moves in right lines? What is said of the number of lines which emanate from a luminous body?

477. *Light has a progressive motion of about one hundred and ninety two thousand five hundred miles per second.*

The estimation of the velocity of light, (which may be classed among the greatest achievements of the human mind,) has been effected in two different ways. The first method is by means of the eclipses of Jupiter's satellites. To render this mode intelligible to those who have not studied astronomy, it may be premised, that the planet Jupiter is attended by four moons, which revolve about their primary, as our moon revolves about the earth. These small bodies are observed, by the telescope, to undergo frequent eclipses, by falling into the shadow which the planet casts in a direction opposite to the sun. The exact moment when the satellite passes into the shadow, or comes out of it, as seen by a spectator on the earth, is calculated by astronomers. But sometimes the earth and Jupiter are on the same side, and sometimes on opposite sides of the sun; consequently, the earth is, in the former case, the whole diameter of its orbit, or about one hundred and ninety millions of miles nearer to Jupiter than in the latter. Now it is found by observation, that an eclipse of one of the satellites is seen about sixteen minutes and a half sooner when the earth is nearest to Jupiter, than when it is most remote from it, and consequently, the light must occupy this time in passing through the diameter of the earth's orbit, and must therefore travel at the rate of about one hundred and ninety two thousand miles per second.* Another method of estimating the velocity of light, wholly independent of the preceding, is derived from what is called the *aberration of the fixed stars*. The full explanation of this method must be referred to astronomy; but it may be understood, in general, that the apparent place of a fixed star is altered from the effect of the motion of its light combined with the motion of the earth in its orbit. It will be remarked, that the place of a luminous object is determined by the direction in which its light meets the eye. But in the case of light coming from the stars, the direction is altered in consequence of the motion of the earth in its orbit, being intermediate between the actual directions of the earth and the light of the star; and the velocity of the earth in its orbit being known, that of light may be computed from the proportional part of the effect produced by it in causing the

With what velocity does light move? How is its progressive motion proved? Explain the method from observations on Jupiter's satellites, and by the aberration of the fixed stars.

* $\frac{190000000}{16.5 \times 60} = 192000$ nearly.

aberration. The velocity of light, as deduced from this method, comes out very nearly the same as by the other. Hence it is inferred that the velocity of light is uniform.

478. *The intensity of light, at different distances from the radiant, varies inversely as the square of the distance.*

Thus, if we carry a given surface, as a leaf of paper, to different distances from a candle, at the distance of six feet the surface will receive only $\frac{1}{4}$ as much light as at the distance of three feet; at twelve feet, or four times as far as at first, the light will be only $\frac{1}{16}$ as intense. Although the intensity of light decreases rapidly as we recede from the radiant, yet the *brightness* of the object suffers little diminution by increase of distance. A candle appears nearly as bright at the distance of a mile as when close to the eye.

479. Light, when it impinges on smooth surfaces, is *reflected* back into the same medium, and when it passes out of one medium into another, it is bent out of its former course, or *refracted*. The laws of reflexion and refraction constitute, severally, important departments of the science of Optics, and to these our attention will now be directed.

CHAPTER I.

OF THE REFLEXION OF LIGHT.

480. *Light is said to be reflected when, on impinging upon any surface, it is turned back into the same medium.*

Instruments employed as reflectors are divided into *mirrors* and *speculums*. The name mirror is applied to reflectors made of glass and coated with quicksilver, as common looking glasses: the word speculum is applied to a metallic reflector, such as those made of silver, steel, tin, or a peculiar alloy called speculum metal. As the light which falls on glass mirrors is intercepted by the glass before it is reflected from the quicksilvered surface, a speculum, or a reflector of polished metal, is that supposed to be employed in optical experiments, unless the

How is the intensity of light at different distances from the radiant? When is light said to be reflected? How is the brightness of a light at different distances?

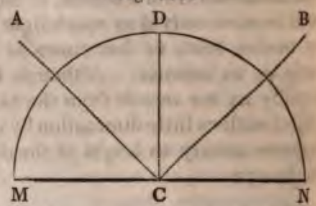
Explain the distinction between mirrors and speculums.

contrary is specified. Such a surface, indeed, is to be understood when the word mirror is used without distinction.

The surface of the mirror or speculum may be either plane, concave, or convex, and the reflector is denominated accordingly.

A ray of light before reflexion is called the *incident* ray. The angle made by an incident ray, at the surface of the reflector, with a perpendicular to that surface, is called the *angle of incidence:* the angle made by the reflected ray with the same perpendicular is called the *angle of reflexion*. Thus, in Fig. 102, if MN represents the reflecting surface, DC a perpendicular to it at the point C, AC the incident, and BC the reflected ray; then ACD will be the angle of incidence, and BCD the angle of reflexion.

Fig. 102.



481. Experiments on light are usually conducted in a room which can be made dark with close shutters, one of which is perforated with a circular hole, a few inches in diameter, for admitting a beam of light. This opening is rendered smaller to any required degree by covering it with a piece of board or metallic sheet, having a smaller aperture. And, as the sun may not shine directly into the shutter at the time required, a mirror is sometimes attached to the outside of the shutter, so contrived, that by means of adjusting screws, it may be made to turn the rays of the sun into the opening, and to give them a horizontal or any other required direction. The course of the rays is rendered palpable to the eye, by the illuminated particles of dust that are floating in the air.

482. *The angles of incidence and reflexion are in the same plane and are equal to each other.*

Let a ray of light AC (Fig. 102.) admitted into a dark chamber as above, be incident upon a horizontal speculum MN at the point C, to which the line CD is perpendicular, and let CB be the reflected ray. Then if the plane surface of a board, or a metallic plate, be made to coincide with the incident ray and the perpendicular, it will be found to coincide also with the reflected ray, showing that the three rays are in the same plane. Again,

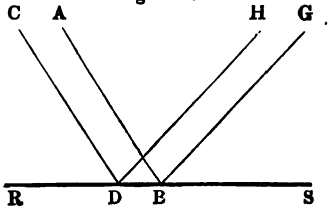
What is the angle of incidence and of reflexion? Explain by the figure. How are experiments on light usually conducted? State the relation between the angles of incidence and reflexion.

if, from the point C, with the radius CA, a circle be described, on measuring the arcs subtended by the angles of incidence and reflexion, they will be found to be exactly equal to each other. The angles of incidence and reflexion are also equal when the reflexion takes place from a concave or convex surface; for the reflexion being from a *point*, the curve and tangent plane at that point coincide, and have both the same perpendicular, namely, the radius of the curve.

Reflexion of Light from Plane Mirrors.

483. *When rays of light are reflected from a plane surface, the reflected rays have the same inclination to one another as their corresponding incident rays.*

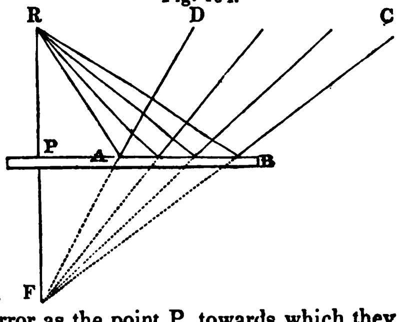
Fig. 103.



When *parallel* rays, as AB, CD, (Fig. 103.) fall upon a plane mirror, as RS, the reflected rays, BG, DH, are also parallel.

Moreover, when the rays *diverge* before reflexion, (Fig. 104,) as RA, RB, they will diverge just as much after reflexion, proceeding in the lines AD, BC, which will appear to come from F, a point just as far behind the mirror as R is before it; or if DA and CB be considered as two *converging* rays, they will converge in the same degree after reflexion in the lines AR, BR, and will meet in R, a point just as far before the mirror as the point P, towards which they tended, is behind it.

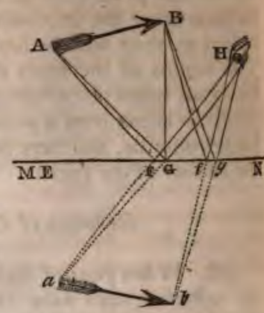
Fig. 104.



484. *When an object is placed before a plane mirror, the image of it appears at the same distance behind it, of the same magnitude, and equally inclined to it.*

Reflexion from Plane Mirrors.—How are parallel rays reflected? Ditto *diverging rays?* Ditto *converging?* Explain by the figures.

Fig. 105.



Let MN, (Fig. 105.) be a plane mirror, and AB an object before it, the eye being situated at H. Now from every point in the object innumerable rays of light are constantly emanating, which striking on all parts of the mirror, are reflected off again in various directions. All that is essential to vision is, that a sufficient number of these should be conveyed to the eye. To avoid the confuson that arises from the representation of a great number of lines, we will consider those rays only which flow from the extreme parts of the object; the rays proceeding from the intermediate points will of course lie between these. From the point A, then, we may conceive of a vast number of rays of light as proceeding to all parts of the mirror, from which they are reflected again in various directions; but those only which fall upon the small part of the mirror FG, namely AF, AG, are conveyed to the eye. These, therefore, are the rays which serve to make the point A visible; and since they come to the eye as though they diverged from the point *a* as far behind the mirror as A is before it, the point A will appear as though it were at *a*. For the same reason the point B will be rendered visible by the rays *f*H, *g*H, which appear to diverge from *b*, a point as far behind the mirror as B is before it. All the other points in the line AB will take their respective places in the line *ab*, which will therefore form an exact image or picture of the object, affecting the eye in the same manner as the object would do in its place. It is important to remember, that how many reflexions soever light may undergo in passing from the object to the eye, *the image will be determined as to position, magnitude, &c. by the manner in which the rays finally reach the eye after the last reflexion.*

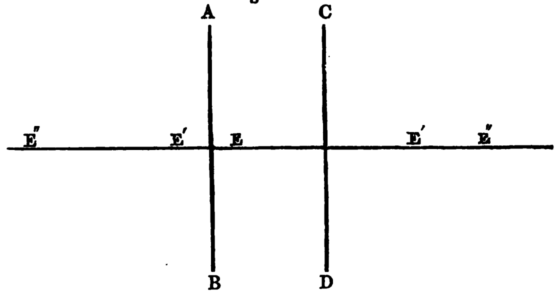
485. When a plane mirror (as a common dressing glass) is turned on its axis, *the image revolves twice as fast as the mirror.* By turning the mirror through 45°, the image is carried through 90°, so that a mirror set at an angle of 45° with the horizon represents horizontal objects in a perpendicular position, and perpendicular objects on a horizontal level.

When an object is placed before a plane mirror where is the image situated? Explain by the figure. What rays finally determine the place of the image? When a plane mirror revolves on an axis how much faster than the mirror does the image revolve?

486. *When an object is placed between two* PARALLEL *plane reflectors, a row of images is formed in each mirror, appearing in a straight line behind each other to an indefinite extent.*

Let there be two plane reflectors, parallel to each other; and let an object, a candle for example, be placed between them. An image of the candle will be formed in each mirror, as far behind it as the object is before it. Again, each of these images becomes in its turn a new object to the opposite mirror, and forms a corresponding image as far behind that mirror as it is itself before it, and thus the images are repeated in a right line until the light becomes too feeble to be visible. Thus, let AB, CD, (Fig. 106.) be two plane mirrors, and E an object between them;

Fig. 106.



two images will be formed of E at E′ and E′; two more of E′ and E′ at E″ E″; and thus a succession of images will arise to an indefinite extent; but since a certain part of the light is lost at every reflexion, each succeeding image is fainter than the preceding. The *Endless Gallery* is formed on this principle. It consists of a box, in the opposite sides of which are placed two parallel reflectors, and between them a number of images are placed, which are repeated in an endless succession.

487. *If an object is placed between two plane reflectors* INCLINED *to each other, the images formed will lie in the circumference of a circle.*

The common dressing glasses which are mounted on mahogany frames, and turn on pivots fixed in the two ends, are convenient for performing this experiment. Two such mirrors may

When an object is placed between two parallel plane reflectors, what images are formed? Explain by the figure. What is the principle of the endless gallery? When an object is placed between two plane mirrors *inclined* to each other, what images are formed?

be placed side by side and a candle set between them. When the mirrors face each other, that is, are parallel, an indefinite number of images of the candle may be seen in each mirror; but on turning the mirrors so as to bring their parallel edges at the bottom near each other, while the upper edges are turned outwards, a circular row of images will be observed, the circle continually enlarging as the mirrors are brought nearer to parallelism, and contracting more and more as the inclination of the mirrors is increased.

488. The degree of perfection in the polish and figure of a plane speculum, may easily be known by observing whether the images seen in all positions, especially in very oblique ones, and from all parts of the speculum, appear exactly equal and similar to the objects; that is, whether the images (more particularly of the most distant objects) in the room, appear naturally, without having any part of them distorted; when this is the case, the speculum may be pronounced to be a perfect one. The straight edges of the window sashes are the best objects for this experiment. A mirror must be exceedingly bad that will distort the face of a person looking into it, because the rays being returned almost directly back to the eye, small aberrations will not be rendered sensible; but let two persons look at each other's image as obliquely as they can, and they will soon perceive whether or not the figure of the speculum is defective. In all speculums, the better they are polished, other circumstances being the same, the brighter will be the images; that is, the more light an eye will receive from a given object, which will enable us to examine the goodness of speculums, as to their polish, whenever we have an opportunity of comparing several of the same sort, and in the same light together. We may also observe that, other things being equal, the darker the color of the speculum is, the better is the polish; for the glass itself can be no otherwise seen than by the reflexions of those particles which have irregular positions with respect to the rest of the surface. But different glasses, though equally well polished, will not always appear equally dark; generally, however the above rule may be observed.

489. It is found by experiment, that when a pencil of light is incident perpendicularly upon *water*, only 18 rays out of 1000

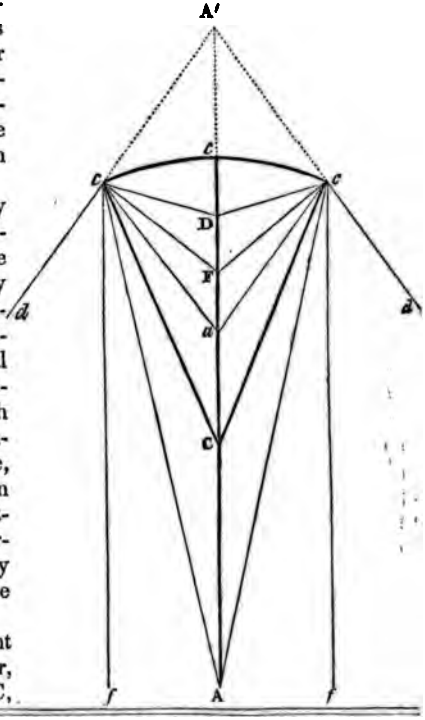
How may the experiment be performed? How may the degree of perfection in the polish and figure of a plane mirror be known? What is the quality of a mirror that distorts the face of a person looking directly into it? How may two persons detect the imperfections of a mirror by looking at each other's images? What is indicated by a dark color in a mirror? *When* a pencil of light falls perpendicularly on water, how many rays *out of 1000* are reflected?

lected, while the greater part of the remaining rays are itted. As the angle of inclination is increased, the pro- 1 of rays reflected is also rapidly increased, till at an of 75°; the reflexion is 211 rays; at 85°, 501; and at 89°,
In *glass* 25 out of 1000 are reflected at a perpendicular nce; and the glass always reflects more light than water, reach very great angles of incidence, such as 87½°, when ects only 584 rays, while water reflects 614.

Reflexion of Light from Concave Mirrors.

. The office of concave reflectors, in general, is to *collect* f light. Hence, when applied to parallel rays, it makes converge to a focus; when applied to rays already conver- it makes them rge more; to di- g rays, it makes diverge less, or omes their di- ncy so com- y as to make parallel, or even rging.
keeping steadily nd the proposi- that the angle the incident ray s with a perpen- ir to the reflect- urface, is equal t which the re- d ray makes with ame perpendicu- n the other side, arious modes in light is reflect- m a concave sur- will be readily stood from the ced figure.
t *c c c* represent oncave mirror, e center is C,

Fig. 107.



w many from glass? *Concave Mirrors.*—What is the general office ncave mirrors? How does it affect parallel, diverging, and converg- ys respectively? Explain from the figure.

and radius of curvature C *c;* (which radius it must be remembered is always perpendicular to the curve;) then the various cases will be as follows:

Parallel rays, *fc*, *fc*, will pass to the other side of the perpendicular and meet in F,* which is half way from the mirror to its center C.

Rays *diverging from a point more remote than the center*, A*c*, A*c*, making a less angle with the perpendiculars than the parallel rays make, will also make a less angle on the other side of the perpendiculars, meeting in *a*, between the focus and the center.

Rays diverging from the *center*, C*c*, C*c*, will be reflected back to the center again.

If we now pass to the other side of the center, we see that rays which diverge from a point between the center, and the focus, as from *a*, converge to a point on the other side of the center, as A. Rays diverging from the focus, go out parallel, as *cf*, *cf*.

Rays that come to the mirror *converging*, as *dc*, *dc*, meet in a point between the focus and the mirror, as at D, and when diverging from this point they return in the lines *cd*, *cd*, appearing to proceed from a point behind the mirror, as A′, which is called the *virtual focus*.

491. The following experiments, which may be easily repeated, will serve to render familiar the different modes in which images are formed by concave mirrors. See Fig. 107.

We will suppose a lighted candle to be placed very near to a concave mirror:—it will form no image before it because the rays go out still diverging, but we see an enlarged image of the candle *behind* the mirror. As the radiant is withdrawn from the mirror towards the principal focus, the image will rapidly recede on the other side, and grow larger and larger until the radiant reaches the focus, when the image will suddenly disappear. On removing the radiant a little farther, the image will be found at a great distance *before* the mirror and very much enlarged. As the radiant approaches the center, the image approaches it rapidly on the other side of it, constantly diminishing in size until they both meet and coincide in the cen-

Where do rays diverging from a point *more remote* than *the center* meet? How are rays from the *center* reflected?—from *between* the *center* and the *focus?*—from the *focus?* How are *converging* rays reflected? Suppose a lighted candle placed before a concave mirror, and state the various appearances at different distances.

* F is called the *focus of parallel rays.*

ter. Removing the radiant still farther, the image appears again between the center and the focus, diminished in size, and slowly approaching the focus as the radiant recedes, but never reaches it, unless when the radiant may be considered as at an infinite distance, as in the case of the heavenly bodies.

One who looks into a concave mirror sees his own face varied in the following manner. When he holds the reflector near to his face, he sees his image *distinct*, because the rays come to the eye diverging (which is their natural state with respect to near objects,) and *enlarged*, because, as the rays diverge less than before, the image is thrown back to a greater distance behind the mirror than the object is before it, and the magnitude is proportioned to that distance. As he withdraws the eye, the image grows larger and larger until the eye reaches the focus. From the focus to the center, no distinct image is seen, because the rays come to the eye converging, a condition imcompatible with distinct vision. At the center the eye sees only its own image, since the image is reflected back to the object and coincides with it. Beyond the center, his face will be seen on the other side of the center before the mirror (though habit may lead him to refer it to a point behind it,) and it will be *diminished*, being nearer to the mirror than the object is, and *inverted*, because an inverted image is formed when the rays are brought to a focus, and this becomes the object which is seen by the eye.*

492. Concave mirrors, in consequence of the property they have of forming images in the air, were in a less enlightened age than the present, frequently employed by showmen for exhibiting surprising appearances. The mirror was usually concealed behind a wall, and the object, which might be a skull, a dagger, &c. was placed between it and the wall and strongly illuminated. The rays proceeding from the object fell upon the mirror, and were reflected by it through an opening in the wall, and brought to a focus so as to form an image in the same room with the spectator. If a fine transparent cloud of blue smoke is raised, by means of a chafing dish, around the focus of a large concave mirror, the image of any highly illuminated object will be depicted in the middle of it with great beauty. A dish of fruit thus represented invites the spectator to taste, but the instant he reaches out his hand a drawn dagger presents itself.

State the various appearances when one holds a concave mirror at different distances. What use has been made of concave mirrors by showmen? *By what means may a dish of fruit be strikingly represented?*

* *These phenomena may be all observed with an ordinary concave shaving glass.*

493. Concave mirrors have been used as *light house reflectors*, and as *burning instruments*. When used in light houses, they are formed of copper plated with silver, and they are hammered into a parabolic form, and then polished with the hand. A lamp placed in the focus of the parabola, will have its divergent light thrown, after reflexion, into something like a parallel beam, which will retain its intensity to a great distance.

When concave mirrors are used for burning, they are generally made spherical, and regularly ground and polished upon a tool, like the specula used in telescopes. The most celebrated of these were made by M. Villele, of Lyons, who executed five large ones. One of the best of them, which consisted of copper and tin, was very nearly four feet in diameter, and its focal length thirty eight inches. It melted the metals, as silver and copper, and even some of the more infusible earths.

Burning mirrors, however, have sometimes been constructed on a much larger scale by combining a great number of plane mirrors. It is supposed that it was a mirror of this kind which Archimedes employed in setting fire to the Roman fleet under Marcellus. Athanasius Kircher, who first proved the efficacy of a union of plane mirrors, went with his pupil Scheiner to Syracuse, to examine the position of the hostile fleet; and they were both satisfied that the ships of Marcellus could not have been more than thirty paces distant from Archimedes.

Buffon, the celebrated naturalist, constructed a burning apparatus upon this principle which may be easily explained. He combined one hundred and sixty eight pieces of mirror, six inches by eight, so that he could by a little mechanism connected with each, cause them to reflect the light of the sun upon one spot. Those pieces of glass were selected which gave the smallest image of the sun at two hundred and fifty feet. With one hundred and fifty four mirrors, he was able to fire combustibles at the distance of two hundred and fifty feet.

Reflexion of Light from Convex Surfaces.

494. The office of a convex reflector is, in general, to *separate* rays of light. Hence, when applied to parallel rays, it makes them diverge, to diverging rays it makes them diverge more, and to converging rays, it makes them converge less, even so

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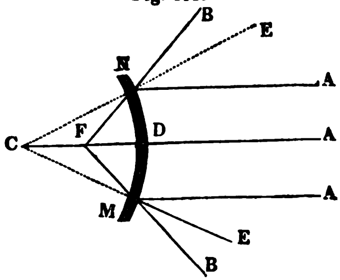
State the use of concave mirrors in light house reflectors. How are they constructed for burning glasses? How were the burning mirrors of Archimedes constructed? How were those of Buffon made? At what distance could he set fire to combustibles? *Convex Mirrors.*—What is the general office of a convex reflector?

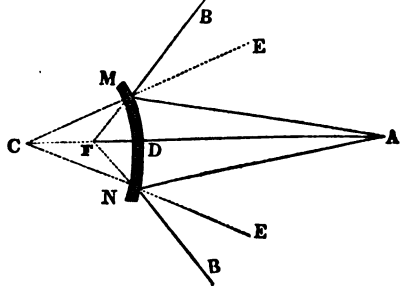
much less, sometimes, as to become parallel or diverging.

Fig. 108.



Thus, (Fig. 108.) the parallel rays AM, AN, falling upon the convex mirror MN, are reflected to the other side of the perpendiculars, CE, CE, into the diverging lines MB, N B, which appear to come from F behind the mirror, which point is called the *virtual focus*.

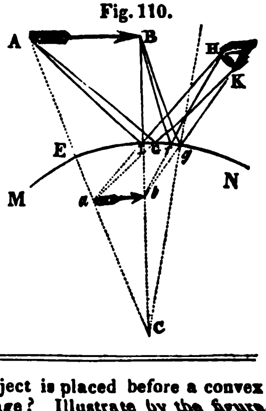
Fig. 109.



In like manner the diverging rays AM, AN, (Fig. 109.) are rendered more diverging than before, and appear to come from a point F nearer the mirror than the focus of parallel rays.

495. *When an object is placed before a convex mirror, the image of it appears nearer to the surface of the mirror than the object, and of a less size.*

Fig. 110.



Thus, (Fig. 110.) AB is seen by the eye at *ab*, and the rays from every point in AB being rendered more divergent by reflexion, they will appear to come from a nearer object; and since the extreme points *a* and *b*, are nearer to each other than AB, the image will be smaller than the object.

Convex mirrors exhibit their peculiar properties in the diminished representation which they give of

Illustrate by the figures. When an object is placed before a convex mirror, *where* and *how large* is the image? Illustrate by the figure. Why are convex mirrors used for parlor glasses?

the furniture of a room; and as objects sometimes appear more interesting and beautiful in miniature, hence the application of such mirrors for parlor glasses.

CHAPTER II.

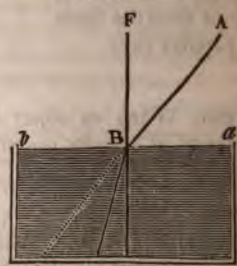
OF THE REFRACTION OF LIGHT, AND OF LENSES AND PRISMS.

496. When light passes out of one medium into another, it is turned out of its course, or *refracted*, according to the following law:

Light, in passing out of a rarer into a denser medium, is refracted towards a perpendicular to that medium; and in passing out of a denser into a rarer medium it is refracted from the perpendicular.

Thus if *ab* (Fig. 111.) be the surface of a vessel of water, a ray of light AB, passing out of air (a rarer) into water (a denser medium) will not pass in the direction of BC, but will be turned towards the perpendicular EB, and pass through the water in the line BD; passing out of water into air, it will be turned away from the perpendicular BF, and pass through the air in the direction of BA.

Fig. 111.



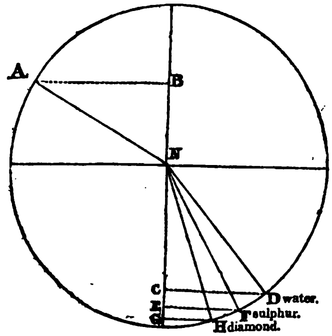
497. We see an example of the foregoing principle in the bent appearance of an oar in the water, the light of the part immersed (by which it is visible) being turned from the perpendicular, and causing it to appear higher than its true place; for objects appear in the direction in which the rays of light emanating from them finally come to the eye. In the same manner, the bottom of a river appears elevated, and diminishes the apparent depth of the stream. Persons have sometimes been drowned in consequence of venturing into water that appeared, from the

Refraction of Light.—When is light said to be refracted? State the *law of refraction?* Illustrate by the figure. Give examples of the displacement of objects by means of refraction.

apparent elevation of the bottom, much shallower than it was. The following ancient experiment illustrates the same principle. If a small piece of silver be placed in the bottom of a bowl, and the eye be withdrawn until the piece of silver disappears, on filling up the bowl with water the silver comes into view.

498. *Transparent bodies differ much among themselves in refracting power.* That is, some bodies have the power of changing the direction of light much more than others. Thus, when a ray of light AN, (Fig. 112.) passes into water, it will be turned into the line ND; if the medium be sulphur, which is denser than water, the direction of the light will be changed more, being refracted farther towards the perpendicular into the line NF; and if the medium be diamond, the change will be greater still. the refraction being in the line NH.

Fig. 112.



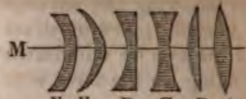
Among different bodies, certain salts of silver and lead, the diamond, phosphorus, and sulphur, rank highest in refracting power; next come the precious gems, and flint glass, containing a large proportion of the oxide of lead, which has a refracting power considerably higher than crown glass, containing less metallic oxide; to which succeed the aromatic oils. Among transparent solids, fluor spar is distinguished for its low refracting powers; but tabasheer, a substance formed from the concreted juice of the Indian bamboo, is more particularly remarkable for this property.

499. LENSES, on account of their extensive use in the construction of optical instruments, require very particular attention in the study of Optics. They are of several varieties, as is shown in the following figure.

Do different bodies refract differently? Illustrate by the figure. What bodies rank highest in refracting power? What second and third? What substances are distinguished for low refracting powers? Lenses.—State the varieties.

A double convex lens (A) is a solid formed by two segments of a sphere applied base to base.*

Fig. 113.



A *plano-convex lens* (B) is a lens having one of its sides convex and the other plane, being simply a segment of a sphere.

A *double concave lens* (C) is a solid bounded by two concave spherical surfaces, which may be either equally or unequally concave.

A *plano-concave lens* (D) is a lens, one of whose surfaces is plane and the other concave.

A *meniscus* (E) is a lens, one of whose surfaces is convex and the other concave, but the concavity being less than the convexity it takes the form of a crescent, and has the effect of a convex lens, whose convexity is equal to the difference between the sphericities of the two sides.

A *concavo-convex lens* (F) is a lens, one of whose surfaces is convex and the other concave, the concavity exceeding the convexity, and the lens being, therefore, equivalent to a concave lens whose sphericity is equal to the difference between the sphericities of the two sides.

A line (MN) passing through the center of a lens perpendicular to its opposite surfaces, is called the *axis*.

500. *The office of a convex lens is to* COLLECT *rays of light.* Hence, when applied to parallel rays, it makes them converge; to diverging rays it makes them diverge less; and to converging rays, it makes them converge more. Moreover, with regard to diverging rays, the degree of divergence may be reduced so much as to render the rays parallel, or even to make them converge, which will depend both on the position of the radiant and on the power of the lens.

On the contrary, *the office of a concave lens is to* SEPARATE *rays of light.* Hence, when it is applied to parallel rays, it makes them diverge; to rays already diverging, it makes them diverge more; and to converging rays, it makes them converge less, become parallel or even diverging.

Define the double convex lens—a plano-convex—a double concave—a plano-concave—a meniscus—a concavo-convex. What is the axis of a lens? What is the office of a convex lens? What is its effect on parallel rays, on diverging, and on converging rays? What is the office of a concave lens?

* Though this is the most common form of the double convex lens, yet it is not essential that the two segments should be portions of the same sphere: they may be segments of different spheres, in which case the curvatures will be unequal on the two sides of the lens.

501. With these general principles in view, we may now advantageously investigate the manner in which IMAGES are formed by means of lenses.

1. If we place a radiant, as a candle, nearer to a lens than its principal focus, then, since the rays go out diverging, no image will be formed on the other side of the lens.

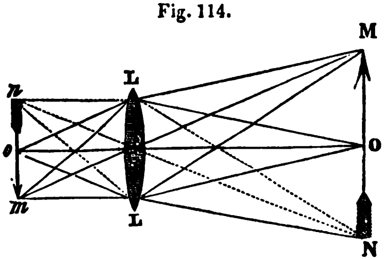
2. If we place the radiant in the focus, the rays will go out parallel, but will still not be collected into a distinct image.

3. If the radiant is removed farther from the lens than its principal focus, then the rays will be collected on the other side of the lens, so as to form a distinct representation of the object.

As this last case is particularly important, since it exhibits the manner in which images are formed by means of convex lenses, let us examine it with more attention.

502. *Rays of light diverging from the several points of any object, which is farther from a convex lens than its principal focus, will be made to converge on the other side of the lens, to points corresponding to those from which they diverged, and will form an image.*

Fig. 114.



Let MN (Fig. 114.) be a luminous object placed before a double convex lens LL. Now every point in the radiant sends forth innumerable rays in every direction, part of which fall upon the lens LL. Each pencil may be considered as a cone of rays, having for its axis the straight line which passes through the center of the lens, which line suffers no change of direction, while those rays of the pencil which strike upon the extreme parts of the lens, form the exterior parts of the cone: all the others are of course included between these. It will be sufficient to follow the course of the central and the two extreme rays. Let ML, MC, ML represent such a pencil. The two extreme rays will be collected by the lens and made to meet in the axis or central ray in some point on the other side,

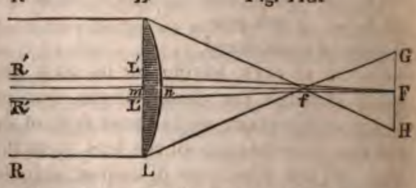
Formation of Images.—State the effects when a candle is placed nearer to a lens than the principal focus—or in the focus—or farther than the focus. State the proposition when rays fall upon a lens diverging from *a point beyond the focus.* Illustrate by the figure.

as at *m*. For the same reason, every other point in the object will have its corresponding point in the image, and all these points of the image taken together, form a true representation of the object. By inspecting the figure, it will be seen that the axes of all the pencils cross each other in the center of the lens; that the image corresponding to the top of the object is carried to the bottom of the image, while that corresponding to the bottom of the object is the top of the image, and, consequently, that the image is inverted with respect to the object. It will be farther seen, that although the individual rays which make up a single pencil are made, on passing through the lens, to converge, yet the axes of all the pencils go out diverging from each other, which carries them farther and farther asunder, the farther they proceed, before they come to a focus. Hence, *the farther the image is formed behind the lens, the greater will be its diameter.*

The diameter of the image will not be altered by changing the area of the lens; for that diameter will be determined in all cases by the distance between the *axes* of the two pencils which come from the extremities of the object and cross each other in the center of the lens. The size of the image, however, will be affected by changing *the convexity of the lens*, while the object remains the same and at the same place.

503. *Rays proceeding from any radiant point, which are refracted by the different parts of the same lens, do not meet accurately in one focus, but their points of meeting are spread over a certain space, whose diameter is called the* SPHERICAL ABERRATION *of the lens.*

Fig. 115.



Let LL be a plano convex lens, on which are incident the parallel rays RL, RL at the extremities, and R′L′, R′L′ near the axis; the axis will proceed on without any change of direction, and the rays which are very near to the axis, being also nearly perpendicular to the refracting surface, sustain only a slight change of direction, sufficient, however, to collect them into a focus at some distance from the lens in the point F. But the rays RL, RL, meeting the refract-

What is the relation between the diameter of the image and the distance *behind* the lens? Is the diameter of the image affected by altering the *area of* the lens? How by altering the *convexity* of the lens? State the proposition respecting *spherical aberration*. Illustrate by the figure.

ing surface more obliquely, are more turned out of their course, and are therefore collected into a focus in some point nearer to the lens than F, as at *f*. The immediate rays refracted by the lens will have their foci between F and *f*. Continue the lines L*f* and L*f*, till they meet at G and H, a plane passing through F, perpendicular to the axis. The distance *f* F is called the *longitudinal spherical aberration*, and GH the *latitudinal spherical aberration.*

It is obvious that such a lens cannot form a distinct picture of any object in its focus F. If it is exposed to the sun, the central parts of the lens L′ *m* L′, whose focus is at F, will form a pretty bright image of the sun at F; but as the rays of the sun which pass through the outer part LL of the lens have their foci at points between *f* and F, the rays will, after arriving at these points, pass on to the plane GH, and occupy a circle whose diameter is GH; hence the image of the sun in the focus F will be a bright disk, surrounded and rendered indistinct by a broad halo of light growing fainter and fainter from F to G and H. In like manner, every object seen through such a lens, and every image formed by it, will be rendered confused and indistinct by spherical aberration.

If we cover up all the exterior portions of the lens, so as to permit only those portions of the rays which lie near the axis to pass through the lens, then the rays all meet at or very near to the point F, and a much more distinct image is formed; but so much of the light is excluded by this process, that the brightness of the image is considerably diminished. The *dimensions* of the image are the same in both cases.

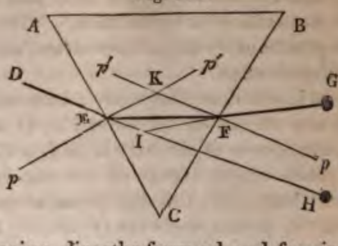
504. The *Prism* is an important instrument in Optics, especially as it affords the means of decomposing light, and enters into the construction of several optical instruments. The *triangular* prism is the only one employed in experiments, and of this nothing more is essential than barely the inclination of two plane transparent surfaces to one another. The optical prism, however, is usually understood to be a piece of solid glass, having two sides constituted of equal parallelograms, and a third side called the *base*. The line of intersection of the two sides is called the *edge*, and the angle contained by the sides, the *refracting angle* of the prism. A straight line passing lengthwise of the prism, through its center of gravity, and parallel

What is the *longitudinal*, and what the *latidudinal* spherical aberration? What will be the effect of covering the exterior portions of the lens? *Prism.*—What is said of its importance? How is the triangular prism *constructed? What is the refracting angle?*

to the edge is called the *axis*. A section made by a plane perpendicular to the axis, is an isosceles triangle. Frequently, the three angles of the prism are made equal to one another, each being 60°.*

Figure 116 represents a section of a prism ABC, of which AB is the *base*, and ACB the *refracting angle*. DE is a beam of the sun's light falling obliquely on the first surface AC, where one portion is reflected but another portion transmitted. The latter portion, instead of passing directly forward and forming an image of the sun at H, is turned upward towards the perpendicular $p p'$, meeting the opposite surface CB in F, where it is again turned upward from the perpendicular $p'p$ in the direction FG, carrying the image of the sun from H to G.

Fig. 116.



CHAPTER III.

OF THE SOLAR SPECTRUM, OF THE RAINBOW, AND OF COLORS IN NATURAL OBJECTS.

505. In tracing the course of rays of light through a refracting medium, we have thus far supposed them to be homogeneous, and to be all affected in the same manner. But in nature the fact is otherwise; that is,

The sun's light consists of rays which differ in refrangibility and in color.

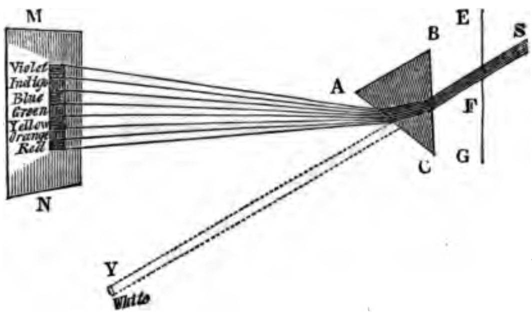
The glass prism, in consequence of the strong refraction of light which it produces, (see Art. 504.) is well fitted for ex-

What is the axis? Describe the mode of making a cheap prism. Show the effect of a prism by the figure. Of what different kinds of rays does the sun's light consist?

* A very convenient prism for common experiments may be constructed as follows: Select two plates of window glass of the best quality, or better, two pieces of looking glass from which the silvering has been removed. The plates may be five or six inches long and one and a half or two inches broad. They are to be united at their edges at an angle of about sixty degrees, and furnished with a tin case, which shall afford the base and the two ends, and a covering for the edge. One of the ends has an orifice with a stopper, for the convenience of filling with a fluid, which may be pure water, or better, a saturated *solution* of the sugar of lead filtered perfectly clear. Projections may be attached to the two ends to serve as handles or as an axis on which the prism may rest on supports. Instead of the tin case, we may employ a block of hard wood, first formed into a triangular prism, and then dug out so as to admit the plates.

periments of this kind. We procure, therefore, a triangular prism of good flint glass, and having darkened a room, admit a sun beam obliquely through a small round hole in the window shutter. Across this beam, near the shutter, we place the prism, with its edge parallel to the horizon, so as to receive the beam upon one of its sides. The rays, on passing through the prism, will be refracted and thrown upwards, as will be rendered evident by conceiving perpendiculars drawn to the surface of the prism at the points of incidence and emergence. If now we receive the refracted rays upon a screen, at some distance, they will form an elongated image, exhibiting the colors of the rainbow, namely, red, orange, yellow, green, blue, indigo, violet, together composing the *prismatic spectrum.* (See Fig. 117.)

Fig. 117.



S, a sun beam.
F, a hole in the window shutter.
ABC, the prism, having its refracting angle ACB downwards.
Y, a white spot, being an image of the sun formed on the floor before the prism is introduced.
MN, the screen containing the spectrum.*

A pleasing way of exhibiting the separate colors of the spectrum, is to throw the prismatic beam on a distant wall or screen, so as to form a long spectrum, and into this beam, at some convenient distance from the prism, to introduce a concave lens

Describe the mode of forming the prismatic spectrum. Illustrate by the figure. What *screen* is used to receive the image?

* The opposite white wall of plaster or stucco, may serve the purpose of a screen; or the screen may be made of a large sheet of white paper; but a convenient screen for *the lecture room is* made by pasting a large sheet of drawing paper to a frame and attaching it to a movable stand.

of a size sufficient to cover each of the different colored pencils successively. The lens will cause the rays of the same color to diverge, and to form a circular image on the screen, which will distinguish them very strikingly from the contiguous portions of the spectrum.

506. *If rays of the same color in the prismatic beam be insulated from the rest and made to pass through a second prism, they are refracted as usual, (the amount of refraction being different for the different colored rays,) but they undergo no farther change of color.*

To perform this experiment, we provide a board, perforated with a small round hole, and mounted on a stand. This screen is placed across the prismatic beam, a little way from the prism, in such a manner as to permit rays of the same color only to pass through the aperture while the other portions of the beam are intercepted. The homogeneous light thus insulated is made to pass through a second prism, and its image is thrown on the wall. The experiment will be more perfect, if the homogeneous pencil be made to pass through a second screen similar to the first, so as to let only the central rays fall upon the second prism. This second refraction produces no change of color. It will be found, however, that, while all other things remain the same, the several images formed of homogeneous rays will occupy different positions on the wall, the red being lowest and the violet highest, and the intermediate colors arranged between them in the order of their refrangibilities. (See Fig. 118.)

Fig. 118.

In addition to the parts of the figure enumerated in Fig. 117, DE represents the first screen, which permits only one sort of rays to pass by a small aperature at G, and *d e* represents a second screen, which permits only the central rays of this pen-

State the proposition respecting the refraction of rays of the same color. Illustrate by the figure.

cil to pass by a small hole at g; $a\,b\,c$ is the second prism, and M is the image of homogeneous light on the wall.

507. *The light of the sun reflected from the first surface of bodies, and also the white flames of all combustibles, whether direct or reflected, differ in color and refrangibility, like the direct light of the sun.*

The truth stated in this proposition was established by Newton, by experiments with the prism, similar to those detailed in connexion with the preceding propositions.

508. *The sun's light is compounded of all the prismatic colors mixed in due proportion.*

If we collect by means of a convex lens, the different colored pencils in the prismatic beam, just after they have emerged from the prism, (see Fig. 117.) the image formed by the lens will be perfectly white. A concave mirror may be used instead of the lens, the image being thrown on a screen. Or the rays after they have passed the prism may be received on a second prism of the same kind, placed near the first, but with its refracting angle in the opposite direction. In this case the second prism restores the light to its usual whiteness.

That all the different colors of the spectrum are essential to the composition of white light, may be rendered evident by intercepting a portion of any one of the colors of the spectrum before they have been re-united, as in the foregoing experiments. Thus, if we introduce a thread or a wire into any part of the prismatic beam between the prism and the lens, the image formed by the lens will be no longer white but discolored. If, instead of the wire, an instrument shaped like a comb with coarse broad teeth, be introduced into the beam, the discoloration of the image is more diversified, the colors of the image being those compounded of the prismatic colors, which are not intercepted by the comb. If the teeth of the comb be passed *slowly* over the beam, a succession of different colors appears, such as red, yellow, green, blue, and purple; but if the motion of the comb be rapid, all these different hues become blended into one by the momentary continuance of each in the eye, and the sensation is that of white light.

What other kinds of light differ in color and refractibility like the direct light of the sun? Of what is the sun's light compounded? How may we restore the colors of the spectrum to the original white? How does it appear that all the colors of the spectrum are essential to white light?

509. For a similar reason, if the colors of the spectrum are painted on a top, in due intensity and proportion, and the top be set to spinning, the sensation will be that of white light. Or the colors of the spectrum may be first laid on a sheet of paper, and this may be pasted on a cylinder of wood, which may be made to revolve on the whirling tables: the result will be the same. Newton tried various experiments with different colored powders, grinding together such as corresponded as nearly as possible to the colors of the spectrum. By this means he was able to produce, from the mixture of seven different colored powders, a *greyish white*, but could never reach a perfectly clear white, owing to the difficulty of finding powders whose colors corresponded exactly to those of the spectrum.

510. *Several of the colors of the spectrum may be produced by the mixture of other colors; as green by the union of yellow and blue, orange by red and yellow, &c.* Experiments were devised by Newton for thus combining the colors of two contiguous spectrums, transferring, for example, the blue of one to the yellow of the other, and forming green by their union. On causing this compound green, however, to pass through the prism, it is resolved into its original colors, yellow and blue, whereas the green of the spectrum is not thus resolved by the prism. Hence Newton infers that the green of the spectrum is not a compound but a simple original color, and so of all the rest.

511. The knowledge of the composition of light, and of the properties of the solar spectrum, naturally lead to an inquiry into the subject of colors, as exhibited in the phenomena of nature. The bright tints of the rainbow, the splendid hues sometimes exhibited by thin plates, as soap bubbles, and finally the diversified colors in all the kingdoms of nature, remain to be accounted for. Some of these we proceed to explain, but others are of a nature too intricate for the present work.

*The Rainbow.**

512. The rainbow, one of the most striking and magnificent of the phenomena of nature, was long ago supposed to be owing

State the experiment with a top or a cylinder,—also Newton's experiments to produce white light. How may individual colors of the spectrum be formed? In what respect does the green of the spectrum differ from the compound green?

**The theory of the Rainbow is necessarily somewhat intricate, and possibly may prove too difficult for the young learner, though we shall endeavor to make it as plain as possible.*

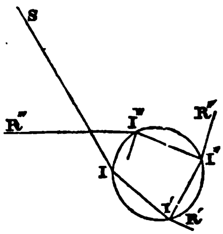
to some modification which the light of the sun undergoes in passing into drops of rain; but the complete development of the causes on which it depends, was reserved for the genius of Newton, and naturally followed in the train of those discoveries which he made upon the prismatic spectrum.

The rainbow, when exhibited in its more perfect forms, consists of two arches, usually seen in the east during a shower of rain, while the sun is shining in the west. These arches are denominated the outer and the inner bow, of which the inner bow is the brighter, but the outer bow is of larger dimensions every way. The succession of colors in the one is directly opposite to that of the other.

513. Drops of rain, though small, are large in comparison with the minuteness of rays of light, and are to be regarded as spheres of water, exerting the powers of refraction and reflexion in the same manner as large globes of water would do. It was, in fact, by investigating the manner in which globular glass vessels filled with water modify the solar rays, that the first hints were obtained respecting the cause of the rainbow. In the year 1611, Antonio de Dominis made a considerable advance towards the theory of the rainbow, by suspending a glass globe in the sun's light, when he found, that while he stood with his back to the sun, the colors of the rainbow were reflected to his eye in succession by the globe, as it was moved higher or lower.

Let us, therefore, in the first place, follow the course of a ray of light through a globule of water. Let SI (Fig. 119.) be a small beam of light from the sun, falling upon the surface of a globule of water at I. Agreeably to what is known of the laws of light in passing out of one transparent medium into another, a portion of the rays would be reflected at I, and another portion would pass into the drop and be refracted to the farther surface at I′. The same effect would recur here, and also at I″, and at I‴; and were the eye situated in either of the lines I′R′, I″R″ or I‴R‴, it would perceive the prismatic colors, because some of the rays

Fig. 119.



Rainbow.—Who first developed its true theory? Of what does it consist? How does the succession of colors in one compare with that in the other? State the experiments of Antonio de Dominis. Explain by the *figure.*

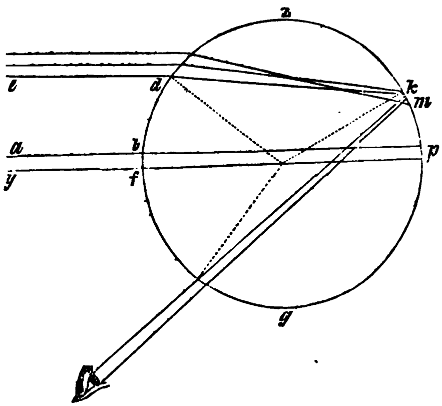
which composed the beam of light that reached the eye would be refracted more than others, and thus the different colors would be made to appear. Or if a screen were so placed as to receive these transmitted rays, a faint spectrum would be formed upon it. Such a progress of a beam of light admitted through the window shutter, and made to fall on a globular vessel of water, may be actually rendered visible by experiment.

514. It may be remarked that but a comparatively small part of the solar rays that shine upon a drop of water, are required in order to produce the mild light of the rainbow, aided as its light is by the dark ground or cloud on which it is usually projected; yet where the number of rays that enter the eye is diminished beyond a certain limit, the light becomes too feeble for distinct vision. It will also be observed, that a considerable portion of light is lost at each successive reflexion that takes place within the drop, so that a certain beam of light, conveyed to the eye after two reflexions, will be much more feeble than the same beam after one reflexion. Indeed, so much of the sun's light is dissipated at the first point of reflexion from the interior surface, added to what is transmitted at the same point, and of course never reaches the eye of the spectator, that, were it not for a great *accumulation* which the sun's rays undergo at a particular point in this drop, whence the light is reflected and conveyed to the eye, the phenomena of the rainbow would not occur. The manner in which this accumulation is effected, is now to be explained.

515. Let $f z p q$ (Fig. 120.) be the section of a drop of rain, $f p$ a diameter, $a b$, $e d$, &c. parallel rays of the sun's light, falling upon the drop. Now $y f$, a ray coinciding with the diameter, would suffer no refraction; and $a b$, a ray near to $y f$, would suffer only a very small inclination towards the radius, so as to meet the remoter surface of the drop very near to p; but the rays which lie farther from $y f$, being inclined towards the radius in a greater angle, would be more and more refracted as they were farther removed from the diameter. The consequence would be, that after passing a certain limit, the rays that lay above that limit would cross those which lay below it, and meet the further surface somewhere between the diameter and the ray which passed through the said limit; that is, all the rays falling on the quadrant $f z$, would meet the circumference

How large a portion of the light that falls on drops of rain goes to form the rainbow? Explain how an accumulation of light takes place in a *certain part of* the drop.

Fig. 120.



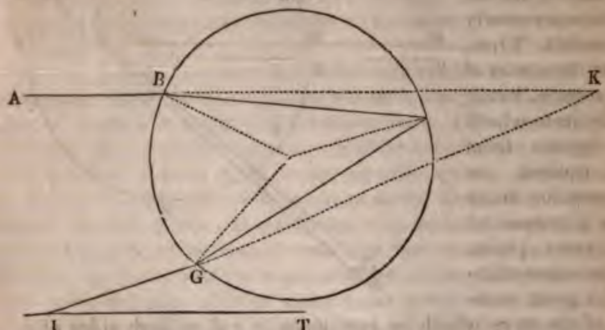
within the arc *k p*. But when a quantity is approaching its limit, or is beginning to deviate from it, its variations are nearly insensible. Thus, when the sun is at the tropics, being the limits to which he departs from the equator, he appears for some time to remain at the same point. In the same manner, a great number of the rays which lie contigious to *e d*, on both sides of it, will meet in very nearly the same point on the concave surface of the drop at *k m*. Consequently, a greater number of rays will be reflected from that point than from any other in the arc. Moreover, proceeding from a single point, they will emerge parallel, and therefore more of them will enter an eye favorably situated, than if they passed out diverging. On both these accounts, it appears that there is a particular point in a drop of rain, where the rays of the sun's light seem to *accumulate*, and are therefore peculiarly fitted to make an impression on the organ of vision. It is found by calculation, that the angle which the incident and emergent rays, in such cases, make with each other, is, for the *red* rays, 42° 2′, and for the *violet* rays, 40° 17′. These are the angles when the rays emerge after two refractions and *one* reflexion: in the case of two refractions and *two* reflexions, the angles are, for the *red* rays, 50° 59′, and for the *violet* 54° 9′.

516. Let us next consider what must be the position of the spectator in order that his eye may receive the emergent rays which make the foregoing angle with the incident rays, and which of course are those which cause the phenomena of the rainbow.

What angle do the incident and emergent rays make with each other in the case of the *red* and the *violet* rays respectively? What must be the position of the spectator with respect to the sun?

The spectator must stand with his back to the sun, and a *line drawn from the sun towards the bow, so as to pass through his eye, will make the same angle with the emergent rays that they make with the incident rays.* Thus, let AB be the incident and

Fig. 121.



GI the emergent ray, and let the angle which these two rays make with each other be AKI; and let IT be a ray passing from the sun towards the bow through the eye of the spectator; then, (since the rays of the sun may be regarded as parallel,) AB and IT are parallel, and the alternate angles AKI and KIT, equal. But AKI is the angle made by the incident and emergent rays, and KIT the angle made by the emergent ray and a line drawn from the sun towards the bow through the eye of the spectator.

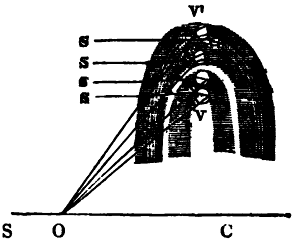
517. *When the sun shines upon the drops of rain as they are falling, the rays which come from these drops to the eye of the spectator after* ONE REFLEXION AND TWO REFACTIONS, *produce the innermost or primary rainbow; and those rays which come to the eye after* TWO REFLEXIONS AND TWO REFRACTIONS, *produce the outermost or superior rainbow.*

Let SOC* be a straight line passing from the center of the sun through the eye of the spectator at O towards the bow,

Where does a line drawn from the sun, through the eye, pass with respect to the bow? Explain by the figure. How are the rays refracted and reflected to produce the inner, and how to produce the outer bow? State the proposition.

*It will be observed that the line SOC is at right angles to the plane of the paper that is, to the plane of the bows.

Fig. 122.



and let SR, SV, be incident rays, which, after one reflexion and two refractions, are conveyed to the eye at O, making (Art. 516.) with SOC angles equal to those formed by the incident and emergent rays. If OV makes with SOC an angle of 40° 17′, and be conceived to revolve around OC, describing the surface of a cone, all the drops of rain on this surface will be precisely in the situation necessary in order that the violet rays, after two refractions and one reflexion, may emerge parallel and arrive at the eye in O, and this will not take place in the same manner in any part of the cloud; so that by means of this species of rays, the spectator will see on the cloud a violet colored arc, of which OC will be the axis, and C the center. He will see, also, an infinity of other concentric arcs exterior to the violet, each one of which will be made up of a single species of rays; and according as these rays are less refrangible, their areas will be of greater diameter, so that the largest, composed of the extreme red, will subtend an angle ROC of 42° 2′. Therefore, the whole width of the colored bow will be 42° 2′—40° 17′, or 1° 45′, the red being on the outside and the violet within.

The contrary order of colors will result from *two reflexions* and two refractions. Let SV′, SR′, be the incident rays, which after two reflexions and two refractions are converged to the eye at O, making (Art. 516.) with SOC angles equal to those formed by the incident and emergent rays, namely 50° 59′ and 54° 9′, and the lines RO′ and VO′, as before, be conceived to revolve around SOC; they will severally meet with all the drops, which having twice refracted and twice reflected the extreme red and violet rays, can transmit them to the eye. Between these two arcs there will be others, exhibiting all the intermediate prismatic colors; and the whole together will form a second bow, whose breadth will be 54° 9′—50° 59′, or 3° 10.

518. The rays, therefore, which come from all the drops which make an angle of 42° 2′ with a line passing from the sun through the eye (which may be called the *axis of vision*) appear

Of how many degrees is the angle contained by lines drawn from the eye to the center and to the top of the bow? What is the width of the *inner and of the outer bow?*

red; and it is obvious that a collection of rays drawn all around this axis from the eye to drops thus situated would form a cone, of which the drops themselves would constitute the base, and of course would form a circle. The same is true of all the other colors which emerge from drops at angles which are different for different colors but constant for the same color. Hence, *the line which passes from the sun through the eye of the spectator, passes also to the center of the bow*, or is the axis of the cone of which the bow itself is the base. If the sun is on the horizon, this axis becomes a horizontal line; consequently, the center of the arch rests on the opposite horizon, and the bow is a semi-circle, of which the highest point has an altitude above the horizon of 42° 2′. If the sun is at this altitude of 42° 2′ above the horizon, then the center of the bow will have the same depression below the opposite horizon, and the circumference, at its highest point, will just reach the horizon. When the sun is between these two points, the elevation of the bow will be the difference between the altitude of the sun and the foregoing angle.

519. When the spectator is on an eminence, as a high mountain, he may see more than half the bow, when the sun is near setting; for the axis will in that case pass to a point above the opposite horizon. Travellers who have ascended very high mountains, have occasionally observed their shadows projected on the clouds below, with their heads encircled with rainbows. In this case, the axis passes to a point above the opposite horizon equal to or greater than the semi-diameter of the bow, so that the whole of the circumference comes into view; and the eye of the spectator being in the axis, the entire bow is projected around that as a center, upon the surface of the clouds.

Colors of Bodies.

520. According to the Newtonian theory, the color of a body depends on *the kind of light which it reflects.* A great number of bodies are fitted to reflect at once several kinds of rays, and consequently appear under mixed colors. It may even happen that of two bodies which should be green, for example, one may reflect the pure prismatic green, and the other

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What is the position of the axis when the sun is in the horizon? What part of a circle is the bow in this case? Where is its center? What is its *altitude* above the horizon? Explain the formation of rainbows around *the heads* of travellers on high mountains?

the green which arises from the mixture of yellow and blue. This quality of selection, as it were, in bodies, which varies to infinity, occasions the different kinds of rays to unite in every possible manner and every possible proportion; and hence the inexhaustible variety of shades which nature, as in sport, has diffused over the surfaces of different bodies.

When a body absorbs nearly all the light that reaches it, that body appears black; it transmits to the eye so few reflected rays, that it is scarcely perceptible in itself, and its presence and form make no impression on us, unless as it interrupts, in a manner, the brightness of the surrounding space.

CHAPTER IV.

OF VISION.

521. As a preparation for studying the optical structure of the eye, and the laws of vision, it will be useful first to learn in what way images of external objects are formed in a dark room, by light admitted through a hole in the window shutter.

522. *A beam of light from the sun, entering into a dark room through a small orifice, and striking upon an opposite wall or screen, forms a circular image on the wall, whatever is the shape of the orifice.*

We will suppose the orifice to be comparatively large, as an inch in diameter, and of a triangular or of an irregular shape; the image formed on the wall will still be circular. For, suppose the orifice to be reduced to a very small circular hole, as a pin hole, (which may easily be done by placing over the orifice a metallic plate, as a sheet of lead, pierced by a pin,) then the rays of the sun passing through this small opening would of course be circular. But the large irregular orifice may be considered as made up of such smaller apertures, or the metallic plate may be conceived to be pierced with an indefinite number of pin holes, and the entire image formed upon the wall may be conceived to be made up of an assemblage of all these

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On what does the color of a body depend? When does a body appear black?

Vision. **[illegible] the proposition respecting the formation of an image of the sun in [illegible] room? Why is the image of the sun on the wall circular with different shaped orifices?**

images of the sun blended with each other, and therefore as bounded by innumerable curve lines composed of the individual circles.

Fig. 123.

If the screen be brought near to the orifice, however, the image will be of the same figure as the orifice; for the rays after they have passed the orifice, must have diverged considerably before the sections that form the image shall afford circles so large, that their blended circumferences shall compose a circular figure. (See Fig. 123.)

If the plane which receives the image, be not parallel to the orifice, the image will be elliptical, being the section of a cone oblique to its axis.

Circular images of the sun are sometimes projected on the ground, through the small openings among the leaves of trees. During an eclipse of the sun, these images copy the figure of the eclipse.

If there be various orifices near to each other, *three*, for example, through which a beam of the sun shines into a dark room, we shall observe at first, at a certain distance, three distinct luminous circles. At a greater distance, these three circles begin to be blended, and finally, on enlarging sufficiently, they unite to form a single circle.

523. *If, instead of a beam of solar light, we admit into a dark room, through an opening in the shutter, the light reflected from various objects without, an inverted picture of these objects will be formed on the opposite wall.*

A room fitted for exhibiting such a picture is called a *Camera Obscura.*

From what has been before explained, it will be readily understood, that from every point in the object, innumerable rays of light proceed and fall upon the window shutter. Of these, however, none can enter the aperture except such as are very near to each other, all others diverging too far to enter a small opening. It is essential to the *distinctness* of the picture that rays which proceed from every point in the object, should be

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What shape is the figure when the screen is oblique to the orifice? Explain the figures projected on the ground under trees in eclipses of the sun? State the proposition respecting the camera obscura. What is *essential to* the *distinctness* of the picture? What to its *brightness?* *Why must* the opening in the window shutter be small?

collected into corresponding points in the image, and should exist there free from any mixture of rays from any other point; and it is essential to the *brightness* of the picture, that as many rays as possible should be conveyed from each point in the object to its corresponding point in the image. To render the picture distinct, therefore, the opening in the window shutter must be small, else the pencils of rays from different points will *overlap* each other, and confuse the picture; but as the orifice is diminished, the brightness of the picture is impaired, since, in this case, a smaller number of rays is conveyed from the object to the image.

These modifications of the picture according to the size of the aperture, may be easily exhibited by beginning with a circular aperture two or three inches in diameter, and reducing its size gradually by covering it with a piece of board, or a metallic plate, perforated with holes of different sizes.*

524. *If, instead of passing through the naked orifice, the rays be received on a convex lens, an inch and a half or two inches in diameter, fixed in the window shutter, a very bright and distinct picture of the external landscape will be formed on a screen placed at the focal distance of the lens.*

The image is *brighter* and more *distinct* than when formed without the aid of the lens, first, because the diameter of the lens may be so great as to receive and transmit a much larger portion of the rays which proceed from each point of the object, than would be compatible with distinctness, if so large a naked aperture were employed; secondly, because the rays of each pencil are brought more accurately to a separate focus; and, thirdly, because the picture being formed nearer to the window shutter, it is smaller, and of course the light, being spread over less space, is more intense.

A convex lens fixed in a ball, is used for this purpose, which is so attached to the opening in the shutter as to be capable of

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What kind of room is suitable for a camera obscura? How must it be fitted up? State the proposition respecting the formation of the picture by the aid of a lens. Why is it brighter and more distinct? What is the scioptic ball?

* A small room, ten feet square, for example, having a window opening towards an unobstructed landscape, may easily be converted into a camera obscura. The perforation in the shutter must be made equidistant from the sides of the room; and from the aperture as a center, with a radius equal to the distance of the opposite wall, describe an arc of a circle, upon which as a base a new concave wall is to be constructed, finished with stucco. The other walls and ceiling are to be colored a dead black, while the concave wall, for receiving the image, is made as white as possible. On admitting the light through an aperture half an inch in diameter, a beautiful and distinct picture will be formed on the opposite wall.

being turned towards different parts of the landscape, like the eye-ball in its socket. Such a lens, with its accompanying parts, is called a *Scioptic ball.*

In a bright sunny day, where the sun is on the side of the house opposite to the shutter, and of course illuminating the sides of objects which face the window, we may form, either with or without the aid of the scioptic ball, a very striking and beautiful picture of external objects, exhibiting each in its relative situation, of a size and brightness corresponding to its distance, with all the colors and the most delicate motions of the landscape. The name *camera obscura*, which appropriately belongs to such a chamber, is also extended to certain boxes in which similar pictures are formed, with peculiar devices for rendering the image erect instead of inverted. The structure of these portable camera obscuras, may be described more particularly among other optical instruments.

The eye is a camera obscura, and the analogy existing between its principal parts, and the contrivances employed to form a picture of external objects, as in the preceding experiments, will appear very striking on comparison.

Fig. 124.

525. The EYE consists of three principal chambers, filled with media of perfect transparency. The first of these media, A, occupying the anterior chamber, is called the *Aqueous Humor*, and consists chiefly of pure water. The cell in which the aqueous humor is contained, is bounded, on its anterior side, by a strong, horny, and delicately transparent coat, *aa*, and is called the *cornea*.

The posterior surface of the chamber A of the aqueous humor, is limited by the *Iris cc*, which is a kind of circular opake screen, consisting of muscular fibres, by whose contraction or expansion an aperture in its center, called the *pupil*, is diminished or dilated according to the intensity of the light. In very strong lights, the opening of the pupil is greatly contracted, so as not to exceed twelve hundredths of an inch in the human eye, while in feebler illuminations it dilates to an opening not exceeding twenty-five hundredths, or double its former

The Eye.—What are its three principal chambers? Describe the aqueous humor—the iris, and the pupil. What changes does the pupil undergo?

diameter. The use of this is evidently to moderate and equalize the illumination of the image on the retina, which might otherwise injure its sensibility. In animals, as the cat, which see well in the dark, the pupil is almost totally closed in the day time, and reduced to a very narrow line ; but in the human eye, the form of the aperture is always circular. The contraction of the pupil is involuntary, and takes place by the effect of the stimulus of the light itself; a beautiful piece of self-adjusting mechanism, the play of which may be easily seen by bringing a candle near to the eye, while directed to its own image in a looking glass. Immediately behind the opening of the Iris, lies the *Crystalline Lens*, B, enclosed in its capsule, which forms the posterior boundary of the chamber A. The figure of the crystalline lens is a solid of revolution, having its anterior surface much less curved than the posterior. The consistence of the crystalline is that of hard jelly, and it is purer and more transparent than the finest rock crystal.

In the crystalline a very curious and remarkable contrivance is adopted, for overcoming or preventing the spherical aberration that (Art. 503.) belongs to lenses of this form, which refract the rays more towards their marginal than near their central parts, and hence do not bring all the rays belonging to one pencil to the same focus. Here the difficulty is obviated by giving to the central portions of the crystalline a proportionally *greater density*, thus increasing its refractive power so as exactly to correspond to that of the other portions of the lens.

The posterior chamber C of the eye is filled with the *Vitreous Humor*. Its name is derived from its supposed resemblance to melted glass ; it is a clear, gelatinous fluid, very much resembling the white of an egg. Rays of light diverging from various objects without, on passing through the aqueous humor, (which is a concavo-convex lens) have their divergency much diminished, or even, in most cases, are rendered converging, and in this state are transmitted through the crystalline, which has precisely such a degree of refractive power as enables it to bring them to a focus at the distance of the retina, which, as a screen, is spread out to receive the image. The retina, as its name imports, is a kind of white net-work, like gauze, formed of inconceivably delicate nerves, all branching from one great nerve O, called the *optic nerve*, which enters the eye obliquely at the inner side of the orbit, next the nose. The retina lines the whole of the cavity C up to *ii*, where the capsule of the

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Describe the crystalline lens. How is it so constructed as to prevent spherical aberration ? Describe the vitreous humor—the retina—the optic nerve.

crystalline commences. Its nerves are in contact with, or immersed in, the *pigmentum nigrum*, a very black velvety matter, which covers the *choriod membrane mm*, and whose office is to absorb and stifle all the light which enters the eye as soon as it has done its office of exciting the retina; thus preventing internal reflexions, and consequent confusion of vision. The whole of these humors and membranes are contained in a thick tough coat, called the *sclerotica*, which unites with the cornea and forms what is called the *white of the eye*.

526. Such, in general, is the structure by which *parallel* rays, and those coming from very distant objects, are brought to a focus on the retina. But there are *special contrivances*, suited to particular purposes, which are no less evincive of design and skill than the general organization of the eye. Some of the most remarkable of these we proceed to mention. The cornea, by protruding, collects the rays of light that come to the eye laterally, and guides them into the eye, thus enlarging the range of vision. It answers to an appendage to the microscope, which will hereafter be described under the name of *field glass*. The motion of the eye-ball, by means of which the pupil may be turned in different directions, conduces to the same purpose. Hence, notwithstanding the minuteness of the aperture which admits the light (and it must be small, otherwise the image will not be distinct) the eye may take in at once, without moving the head, a horizontal range of 110° and a vertical range of 120°, namely, 50° above, and 70 below a horizontal line.

527. As the radiant approaches the lens, the image recedes from it on the other side; (see Fig. 114;) and in our experiments on the formation of images, we are obliged either to change the place of the screen every time the distance of the radiant is altered, or to substitute a new lens which will either throw back the image as much as the increased distance of the radiant brings it forward, or which brings the image as much nearer as the altered place of the radiant tends to carry it off. How then is the distinctness of the image maintained in the eye, notwithstanding the immense variety in the distances of objects? We can conceive of but two ways in which this can be accomplished; either by lengthening or shortening the di-

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Describe the pigmentum nigrum—the choroid membrane—the sclerotica. What special contrivance do we observe in the eye for particular purposes? What is the greatest range of vision which the eye can take in at once? How is the distinctness of the image maintained in regard to objects at different distances?

ameter of the eye in the direction of its axis, so as to alter the distance of the retina from the cornea and crystalline, or by altering the curvature of the refracting lenses themselves, increasing their convexity for near objects, and lessening it for objects that are more remote. Perhaps both causes may operate, but the effect is believed to be produced chiefly by the latter cause, namely, change of figure in the refracting lenses. On this subject, Sir J. Herschel remarks, that it is the boast of science to have been able to trace so far the refined contrivance of this most admirable organ; not its shame to find something still concealed from its scrutiny; for, however anatomists may differ on points of structure, or physiologists dispute on modes of action, there is that in what we *do* understand of the formation of the eye so similar, and yet so infinitely superior, to a product of human ingenuity,—such thought, such care, such refinement, such advantage taken of the properties of natural agents used as mere instruments for accomplishing a given end, as force upon us a conviction of deliberate choice and premeditated design, more strongly, perhaps, than any single contrivance to be found, whether in art or nature, and render its study an object of the deepest interest.

528. Writers on comparative anatomy express the highest admiration of the adaptation of the eyes of different animals to the media in which they respectively live, and to the peculiar wants or habits of each. Thus the crystalline lens of the fish is formed with peculiar reference to the refracting properties of water. In the human eye, this lens has a refractive power only a little greater than that of water; but since the light passes out of a much rarer medium, (air,) such a density is sufficient to bring the rays to a focus; but were the density of the crystalline lens in the eye of the fish no greater than in the human eye, receiving the light from a medium (water) almost as dense as itself, it would be unable to give that change of direction to the rays which would be essential to distinct vision. But provision is made for this exigency by giving to the crystalline lens a much greater density, and of course a higher refracting power, which enables it completely to fulfil its purpose.

Animals which have occasion to see in the dark, as the owl and the cat, have the power of opening or closing the pupil to a much greater extent than man. By this means, they are

What is said of the perfection of structure in the eye? What peculiarity has the eye of a fish? Also of the cat or the owl?

enabled in the dark to collect a far greater number of rays of light. But as such an expansion of the pupil would, in broad day light, endanger the safety of eyes of such peculiar delicacy, the iris closes over the aperture and diminishes it with every increase in the intensity of the light, a change which is involuntary on the part of the animal. In animals, as birds, which pounce upon their prey, the pupil of the eye is elongated perpendicularly, while in those that ruminate, as the ox, it is elongated horizontally; being, in each case, exactly adapted to the circumstances of the animal.

529. The images of external objects are of course formed *inverted* on the retina, and may be seen there by dissecting off the posterior coats of the eye of a newly killed animal, as an ox, and exposing the retina and choroid membrane from behind, like the image on a transparent screen, seen from behind. The appearance is particularly striking and beautiful when the eye is fixed like the scioptic ball, in the window shutter of a dark room. It is this image, and this only, which is *felt* by the nerves of the retina, on which the rays of light act as a stimulus; and the impressions therein produced are thence conveyed along the optic nerve to the sensorium, in a manner which we must rank at present among the profounder mysteries of physiology, but which appear to differ in no respect from that in which the impressions of the other senses are transmitted. Thus, a paralysis of the optic nerve produces, while it lasts, total blindness, though the eye remains open, and the lenses retain their transparency; and some very curious cases of half blindness have been successfully referred to an affection of one of the nerves without the other. On the other hand, while the nerves retain their sensibility, the degree of perfection of vision is exactly commensurate to that of the image formed on the retina. In cases of *cataract*, when the crystalline lens loses its transparency, the light is prevented from reaching the retina, or from reaching it in a proper state of regular concentration; being stopped, confused, and scattered, by the opake or semi-opake portions it encounters in its passage. The image, in consequence, is either altogether obliterated, or rendered dim and indistinct. If the opake lens be extracted, the full perception of light returns; but one principal instrument for producing the convergence of the rays being removed, the image, instead of being formed *on* the retina, is formed considerably *behind*

What is the position of the image on the retina? How may it be seen in the eye of an ox? What is the effect of a paralysis of the optic nerve? What is the disease called cataract?

it, and the rays being received on it in a state of convergence, before they are brought to a focus, produce no regular picture, and therefore no distinct vision. But if we give to the rays before they enter the eye, a certain degree of convergence, by the application of a convex lens, so as to render the lenses of the eye capable of finally effecting the exact convergence of the rays upon the retina, distinct vision is the immediate result. This is the reason why persons who have undergone the *operation for the cataract*, (which consists either in totally removing, or in putting out of the way, the opake crystalline) wear spectacles unusually convex. Such glasses perform the office of an artificial crystalline. An imperfection of vision similar to that produced by the removal of the crystalline, is the ordinary effect of old age, and its remedy is the same. In aged persons, the cornea loses something of its convexity, or becomes flatter. The refracting power of the eye is by this means diminished, and a perfect image can no longer be formed on the retina, the point to which the converging rays tend being beyond the retina. The deficient power is supplied by a convex lens, in a pair of spectacles, which are so selected and adapted to the eye, as exactly to compensate for the want of refracting power in the eye itself, and thus the rays are brought to a focus at the retina, where alone a distinct image can be formed.

530. Near sighted persons have their eyes too convex, forming the image too soon, or before the rays reach the retina. Concave glasses counteract this effect. Rare cases have occurred where the cornea was so very prominent as to render it impossible to apply conveniently a lens sufficiently concave to counteract its action. Such cases would be accompanied with immediate blindness, but for that happy boldness, justifiable only by the certainty of our knowledge of the true nature and laws of vision, which in such a case has suggested the opening of the eye and removal of the crystalline lens, though in a perfectly sound state. Other defects of eye sight, whose cause has been ascertained to depend on mal-conformation of the cornea, or some other parts of the eye, have sometimes been remedied by adapting to them glasses of a peculiar construction, possessing optical properties adapted to the particular defects they were required to remedy.

How is cataract remedied? Why do persons that have had the cataract wear very convex glasses? Why does old age require convex glasses? What is the defect of near sighted persons?

531. *The estimation of the* DISTANCES *and* MAGNITUDES *of objects is not dependent on optical principles alone, but the information afforded by the eye, is taken in connexion with various circumstances that influence the mind in judging of these particulars.*

In the first place, we judge of the distance of an object by the *inclination of the optic axes*, which is greater for nearer objects and less for objects more remote. But beyond a certain distance, this method is very indeterminate, since great intervals among remote objects would scarcely affect the inclination of these axes. In the second place, we judge of distance by the *apparent magnitude of known objects*; as when a ship of large size, or a high mountain, appears comparatively small, we refer it to a great distance. We are also frequently deceived in our estimate of distance when we are approaching large objects, as a great city, or a lofty mountain: we fancy they are nearer than they actually are. In the third place, we estimate the distance of objects by the degree of *distinctness of the parts*, or *brightness of the colors.* Thus, a smoky mountain is referred to a great distance;* a mountain whose sides are precipitous and bare (especally where the rocks have a new and fresh appearance in consequence of having been quarried for use) appears nearer than the reality: vessels, or steam boats, seen through a mist in the night have sometimes run foul of each other, being supposed by the pilots to be much farther off, in consequence of the indistinctness of their appearance. In the fourth place, our estimate of distance is affected by the *number of intervening objects.* Hence, distances upon uneven ground do not appear so great as upon a plain; for the valleys, rivers, and other objects that lie low are many of them lost to the sight. On this principle, the breadth of a river appears less when viewed from one side than from the center; a ship appears nearer than the truth to one unaccustomed to judge of distances on the water; and the horizontal distance of the sky appears much greater than the vertical distance, whence the aerial vault does not present the appearance of a hollow hemisphere, but of such a hem-

State the proposition respecting the magnitudes and distances of objects. In what cases is the visual angle a measure of distance? When do we infer that a large ship is at a great distance? How do we judge of the distance of mountains? What influence have intervening objects? Give examples.

* This appearance exhibits the true color of the atmosphere, becoming visible in consequence of the extent of the stratum, and the dark ground which the mountain affords upon which to view it.

isphere much flattened in the zenith, and spread out at the horizon.

532. A similar variety of circumstances affects our estimate of the *magnitudes* of bodies seen at different distances. First, the *visual angle*, that is, *the angle subtended by the object at the eye*, determines the size of objects that are near; but it is scarcely any guide to the dimensions of remote objects, since all such objects subtend angles at the eye comparatively very small. Thus, on this principle, a fly within a few inches of the eye would appear larger than a ship of war at some distance on the water. A giant nine feet in height, but thirty feet off, would appear no larger than a child three feet high seen at the distance of ten feet. But as this result is not conformable to experience, it is evident that we must have means of judging of the magnitudes of objects, besides that derived from the visual angle. If the giant were to remove from the distance of ten feet from the eye to that of thirty feet, his image on the retina would be only one third as long as before; but, on the other hand, the distance is trebled, and the sort of combination that takes place in us of the two impressions, the one of magnitude, the other of distance, is like the constant product of two quantities, of which one increases in the same ratio as the other diminishes; whence the giant would appear constantly of the same height, at whatever distance from us he was seen.

533. This corrected result, however, we can make only in cases when we are familiar with the actual size of the body. When not thus familiar, we rely too much on the visual angle, and are thus often greatly deceived. A speck on the window, being at the instant supposed to be an object on a distant eminence, is magnified in our estimation into a body of extraordinary size; (as a line half an inch long into a may-pole;) or distant objects supposed to be very near appear to be of an exceedingly diminutive size. Secondly, the effect of *contrast* is visible in our estimation of the magnitudes of bodies, a given object appearing much below its ordinary size, when seen by the side of those of very great magnitude. Men quarrying stone at the base of a high mountain, sometimes appear at a little distance like pigmies, partly from the effect of contrast, but more perhaps from the impression which the mountain gives us of their being nearer

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State the several ways of judging of the magnitudes of objects. How far is the visual angle a criterion. State the examples of a fly and a ship of war—*of a child and a giant.* To what bodies does this rule apply? What *is the effect of contrast?*

than they actually are. Thirdly, objects seen at an angle considerably above or below us, as a man on top of a spire, or a river in a deep valley seen from the top of a mountain, appear greatly diminished. In these cases, since there are no intervening objects to aid us in estimating the distance, we estimate it loo low, and hence (Art. 531.) the object appears less than the reality. Moreover, being seen *obliquely*, its apparent dimensions are diminished on this account, the apparent diameter being determined by the line into which the object is projected perpendicular to the object of vision. Hence, children judge much less accurately both of distances and of magnitudes than adults, and blind persons suddenly restored to sight have usually displayed an utter inability to judge of these particulars.

CHAPTER V.

OF MICROSCOPES.

534. *The Microscope is an optical instrument, designed to aid the eye in the inspection of* MINUTE *objects.*

Telescopes, on the other hand, assist the eye in the examination of *distant* bodies. These two instruments have, probably, more than any other, extended the boundaries of human thought, and no small part of the labor which has been bestowed upon the science of optics, has had for its ultimate object their improvement and perfection.

With the hope of making the learner well acquainted with the principles of the microscope, we shall begin with those varieties of the instrument which are the most simple in their construction, and successively advance to others of a more complicated structure.

535. The simplest microscope is a double convex lens. This, it is well known, when applied to small objects, as the letters of a book, renders them larger and more distinct. Let us see in what manner these effects are produced. When an object is brought nearer and nearer to the eye, we finally reach a point

How is the size of objects when above or below us? *Microscopes.* Define the microscope. What is said of the utility of the microscope and the telescope? What is the simplest form of the microscope? Explain the principles on which it acts.

within which vision begins to grow imperfect. That point is called *the limit of distinct vision.* Its distance from the eye varies a little in different persons, but averages (for minute objects) at about *five inches.* If the object be brought nearer than this distance, the rays come to the eye too diverging for the lenses of the eye to bring them to a focus soon enough, that is, so as to make the image fall exactly on the retina. Moreover, the rays which proceed from the extreme parts of the object, meet the eye too obliquely to be brought to the same focus with those rays which meet it more directly, and hence contribute only to confuse the picture. We may verify these remarks by bringing gradually towards the eye a printed page with small letters. When the letters are within two or three inches of the eye, they are blended together, and nothing is seen distinctly. If we now make a pin hole through a piece of paper, (black paper is preferable,) and look at the same letters through this, we find them rendered far more distinct than before at near distances, and larger than ordinary. Their greater *distinctness* is owing to the exclusion of those oblique rays which, not being brought by the eye to an accurate focus with the central rays, only tend to confuse the picture formed by the latter. As only the central rays of each pencil can enter so small an orifice, the picture is made up, as it were, of the *axes* of all the pencils. The *increased magnitude* of the letters is owing to their being seen nearer than ordinary, and thus under a greater angle, an increase of the visual angle having much influence in our estimate of the magnitude of near objects, though it has but little influence in regard to remote objects. (Art. 532.)

536. A convex lens acts on much the same principles, only it is still more effectual. It does not *exclude* the oblique rays, but it diminishes their obliquity so much, as to enable the eye to bring them to a focus, at the distance of the retina, and thus makes them contribute to the brightness of the picture. The object is magnified as before, because it is seen nearer, and consequently under a larger angle, so that the eye can distinctly recognize minute portions, which were before invisible because they did not occupy a sufficient space on the retina. The power of a lens to accomplish these purposes, will obviously depend on its refractive power; and this, (supposing the material of which the lens is made to remain the same,) will depend on its increased sphericity, and diminished focal

To what is the greater distinctness owing—to what the greater magnitude when objects are viewed through a pin-hole? How does the convex lens act?

distance. Lenses of the smallest focal distance, therefore, other things being equal, have the greatest magnifying power, and, therefore, spherules or perfect spheres have the highest magnifying powers of all. When the radiant is situated in the focus of a lens, the rays go out parallel. (Art. 501.) When thus received by the eye, they are capable of being brought to a focus by it, and of forming a distinct image. Hence, by means of a lens, an object may be seen distinctly when it is exceedingly near to the eye, provided it be situated in the focus of the lens. The magnifying power of a lens, therefore, depends on the ratio between its focal distance and the limit of distinct vision. The latter being five inches, a lens whose focal distance is one inch, by bringing the object five times nearer, magnifies its linear dimensions in the same ratio, and its superficial dimensions in the ratio of the square. Thus, in the case supposed, an object would appear five times as long and broad, and have twenty-five times as great a surface. Lenses have been made capable of affording a distinct image of very minute objects, when their focal distances were only $\frac{1}{60}$ of an inch. In this case, the magnifying power would be as $\frac{1}{60}$: 5, which is as 1 to 300, or as 1 to 90000 in surface.

537. When, however, an object is so near to the eye, a very minute space covers the whole field of vision, and it is only the minutest objects, or the smallest parts of a body, that are visible in such microscopes. The extent of parts seen by a microscope is called the *field of view*. A microscope of small focal distance has a proportionally small field of view. Moreover, since, when the object is so near to the lens, the rays of light strike the lens extremely diverging, only the central rays of each pencil can be brought accurately to a focus. The more oblique rays, therefore, must be excluded by covering up all but the central portions of the lens, by which means the brightness of the image is diminished. The part of a lens through which the light is admitted, is called its *aperture*. The aperture of a lens of small focal distance and high magnifying powers, must of necessity be small, and one of the principal difficulties in the use of such microscopes, is the want of sufficient light. Hence, microscopes of different focal distances are required for differ-

What lenses have the greatest magnifying power? Why can an object be seen so much nearer the eye by aid of the microscope? On what does the magnifying power of a lens depend? What is the smallest focal distance? How great is the magnifying power of such a lens? Define the *field of view*. What microscopes have a small field of view? Why are microscopes of small focal distance apt to be deficient in light? Define the *aperture*.

ent purposes. Where we wish to view a large field at once, we must use a lens which has a large field of view, and of course but comparatively small magnifying powers. Such are the glasses used by watchmakers and other artists. Microscopes which magnify but little, but afford a large field of view, are called *magnifiers* or *magnifying glasses*. Such are the large lenses employed for viewing pictures. But for inspecting the minute parts of a small insect, we require a much higher power; and, the object being very small, a large field of view is not necessary. The only difficulty to be obviated is the want of light; and this evil is remedied, either by placing the object in the sun, or by condensing upon it a still stronger light, by means of apparatus specially adapted to that purpose, which will be described hereafter.*

538. Among the most distinguished achievements of philosophical artists, in our own times, has been the formation of microscopes out of the hardest precious gems, especially the *diamond* and the *sapphire.* The diamond seems to unite in itself almost every desirable quality for this purpose. It will be recollected that this substance is distinguished for its high refractive powers; hence, a given refracting, and of course magnifying, power may be attained with a lens of less curvature, and consequently subject to less *spherical aberration*, than glass lenses of the same power. Indeed, it is estimated, that the indistinctness arising from spherical aberration, is in a diamond lens only $\frac{1}{20}$th as great as in a glass lens of equivalent power. The sapphire has analogous properties, as also the garnet; and pure rock crystal (quartz) is much esteemed for refracting lenses; but some of the pellucid gems are unsuitable for this purpose on account of their possessing the property of giving double images. The comparative curvature and thickness of three lenses of the same refracting power, made respectively of diamond, sapphire, and glass, are exhibited in the following diagrams.

Fig. 125.

Glass. Sapphire. Diamond.

What microscopes are called magnifying glasses? How is the want of light in large magnifiers obviated? What is said of the diamond and sapphire microscopes?

* *A convenient pocket microscope is sometimes sold in the shops, consisting of a slide of ivory or horn, two or three inches in length, in which are set three or four lenses of different powers, adapted to various purposes.*

Since, also, a diamond lens admits of being made much thinner than a glass lens of the same power, the loss of light by absorption is far less, and the *brightness* of the image is proportionally augmented.

539. Another distinguished and valuable property of the diamond is, that it combines with a high refractive, a *low dispersive power*. By dispersive power it will be observed, is meant the power of separating the different colored rays; that is, of decomposing common light into its prismatic elements. Hence, diamond lenses are naturally nearly *achromatic*, or afford images which are destitute of color. But while these favorable qualities were known to appertain to the diamond, which, taken in connexion with its great transparency and purity of structure were observed to fit it admirably for microscopes of great magnifying powers, yet the extreme hardness of the substance seemed to render the difficulty of grinding it into the requisite shape almost insuperable. This difficulty has, however, within a few years, been completely overcome by Mr. Pritchard, an eminent English artist, who has constructed a number of diamond and sapphire microscopes, whose performances have equalled the most sanguine expectations.

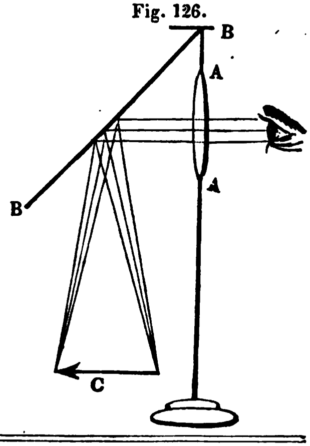
540. A drop of a transparent liquid may be easily converted into a magnifier, constituting a *Fluid Microscope*. The simplest kind of fluid microscope is formed by drilling a small hole in a plate of brass or lead, and applying to it a drop of water from the point of a pin. If the plate be hollowed out on both sides around the aperture, the water will spontaneously assume the shape of a convex lens. Water, however, possessing only a comparatively low refracting power, is less adapted to this purpose than several other fluids, particularly certain transparent balsams and aromatic oils. Sulphuric acid and castor oil answer well, but turpentine varnish and Canada balsam are preferred, especially because as they dry they become indurated, and form permanent microscopes. Instead of the aperture in a metallic plate above described, a small plate of glass may be employed, in which case it is only necessary to drop the varnish or balsam on the surface of the plate; and it will assume the figure of a plano-convex lens. The power of the microscope may be varied by employing a larger or a smaller

What peculiar properties has the diamond for this purpose, in regard to aberration, brightness, achromatic quality, &c.? What difficulty attends the manufacture of diamond microscopes? How are fluid microscopes constructed? What fluid is preferred?

drop, or by suffering it to spread itself on the upper or on the under surface, since the curvature of the drop, and of course its focal distance, is modified by each of these circumstances.

541. The PERSPECTIVE GLASS, which is used for viewing pictures, affords another example of the application of the simple microscope. It consists of a large double convex lens fixed in a frame in a vertical position, from the top of which, on the back side, proceeds a plane mirror which is fixed at an angle of 45° with the horizon, and of course it makes the same angle with the lens. Pictures to be viewed are placed in an inverted position, (that is, with the top towards the spectator,) on a table at the foot of the instrument. The mirror, being set at an angle of 45° with the horizon, renders horizontal objects erect. (Art. 53.) Its office, therefore, is merely to give a proper *direction* to the rays of light from the picture as they enter the lens, causing them in fact, to come to the lens in the same manner as they would do were the mirror removed and the picture set up in a vertical position, parallel to the lens, at a distance from the lens equal to the length of any ray, measured from the picture to the mirror and from the mirror to the lens. (Art. 530.) Again, in order that the image may be erect, it is necessary that the picture should be placed with its top towards the observer; for since the image of every point in the picture is just as far behind the mirror as the point is before it, those parts of the picture which are designed to occupy the highest parts of the image must be farthest below the mirror. This will be understood from the following diagram.

Fig. 126.



AA, a convex lens fixed vertically in a frame.

BB, a plane mirror making with the horizon an angle of 45°.

C, an object placed horizontally upon the table, the upper part being towards the observer.

The object will be reflected by the mirror into a perpendi-

Perspective glass—describe it—How are the pictures placed? What is the *office of the mirror*, and that of the lens? Describe it from the *figure?*

cular position, and its rays will, therefore, fall on the lens in the same manner as they would were it actually situated perpendicularly, and no mirror were employed. Consequently, if the distance of C from the lens be equal to the focal distance of the lens, the rays will come to the eye parallel, and a distinct and magnified image will be formed.

When the glass is of good quality, and the picture executed agreeably to the rules of perspective, the various parts are exhibited in their natural positions, and at their relative distances, so as greatly to improve the view. The greater distinctness of the parts, and more natural distribution of light and shade than what attends the naked view, is owing not only to the increased magnitude and to the greater quantity of the light emitted from the picture, which is collected by the lens and conveyed to the eye, but also to the separation of this portion of light from that which proceeds from various other objects. The lens both conveys more of the light of the picture to the eye than would otherwise reach it, and conveys it unmingled with extraneous light. The importance of the latter circumstance is manifested even by looking at the picture through an open tube, or through the hand so curved as to form a tube.

542. The microscopes hitherto examined are such as are designed to be interposed between the eye and the object to be viewed, the latter being placed in the focus of parallel rays of the lens, or a little nearer to the lens than that focus, so that the rays of the same pencil may come to the eye either parallel or with so small a degree of divergency, that the lenses of the eye shall be competent to make them converge and form an image on the retina. In this case, as the rays come to the eye in the same manner as rays from larger objects, at a greater distance, seen without the aid of a lens, the position of the object is not changed; that is, it is seen erect. Single microscopes, however, are also employed to form a magnified image on a wall or screen, which is seen by the eye instead of the object itself. Two celebrated instruments, the Magic Lantern and the Solar Microscope, magnify their objects in this manner, in the construction of which the principles under review are happily exemplified.

543. From what has been already learned respecting lenses, the following points will be readily comprehended, being for the

To what is the greater distinctness of parts owing? Why does it improve the distinctness of a picture to look through the hand or an open *tube?* Why do objects seen through single microscopes appear erect?

most part a recapitulation of principles already explained and demonstrated.

If, in a dark room, we place before a convex lens any luminous object, as a candle, we shall observe the following phenomena. (See Art. 501.)

1. If the radiant be placed nearer to the lens than its focus, since the rays will go out diverging, no image will be formed on the other side of the lens.

2. Even when the radiant is in the focus, so that the rays go out parallel, they never meet in a focus, and of course never form an image.*

3. But when the radiant is farther from the lens than its focus, the rays converge on the other side, those of each pencil proceeding from the same point in the object, being accurately united in one point in the image, and occupying that point alone, without the interference of rays from any other point.

4. The axes of the rays from the extreme parts of the object cross each other in the center of the lens. Hence, they form an image *inverted* with respect to the object; and, although the rays which make up any individual pencil are made to *converge* by the lens, yet the axes (which determine the magnitude of the picture) diverge from each other after crossing at the center of the lens, and hence the image is greater in proportion as it is formed at a greater distance from the lens. When the object is only a little farther off from the lens than its focus, the image is thrown to a great distance, and is proportionally magnified. As the object is separated farther from the lens (which may be effected either by withdrawing the object from the lens or the lens from the object) the image is formed at a less distance, and is of a diameter proportionally less. (See Art. 502.) Suppose now that we employ a magnifier of so small focal distance, that when the object is placed within one tenth of an inch of the lens, the image is formed on the other side upon a screen or wall at the distance of twenty feet; the object will be magnified in the ratio of $\frac{1}{10}$ to $(20 \times 12 =)240$; that is, the image will be 2,400 times greater than the object in diameter, and

Magic Lantern. Recapitulate the leading principles essential to an understanding of this instrument. When the radiant is nearer the lens than the focus, in the focus, and farther than the focus, where do the axes of the several pencils cross each other? Why is the image inverted? Why is it enlarged? What is the magnifying power when the distance of the focus is 1-10 inch, and that of the image 20 feet?

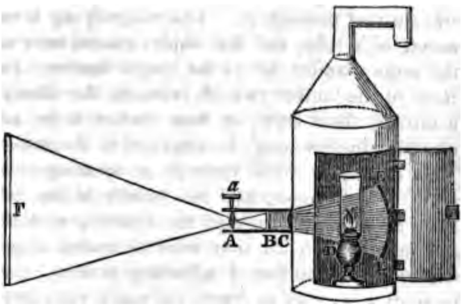
* It will be remarked, that when the single microscope is used as an eye glass, the eye itself brings the parallel rays to a focus and forms the image.

5,760,000 times greater in surface. It would seem, therefore, as if nothing more were necessary in order to form magnified images of objects, than a dark room, a convex lens, and a screen or wall for the reception of the picture. It must be remarked, however, that when the light which proceeds from the object is diffused over so great a space, its intensity must be greatly diminished, so as to be either incapable of affording a picture which shall be visible at all, or at least sufficiently bright for the purposes of distinct vision. This difficulty is remedied by *illuminating the object;* and it is for this purpose, that most of the contrivances employed in the magic lantern and solar microscope are designed.

544. The MAGIC LANTERN consists of a large tin canister, either cylindrical or cubical in its figure, having an opening near the bottom into which air may enter freely to supply the lamp, and a chimney proceeding from the top and bent over so as to prevent the light of the lamp from shining into the room. The lantern has a door in the side which shuts close, the object being throughout to prevent any light from escaping into the room except what attends the picture. The room itself is made as dark as possible ; or, what is better, the experiments are performed by night. In front of the lantern is fixed a large tube, at the open end of which is placed the magnifying lens. In the same tube, at a distance from the lens somewhat greater than the focal distance, the object is introduced, which is usually some figure painted on glass in transparent colors, the other parts of the glass being blackened so that no light can pass through except that which falls on the object and illuminates it, by which means we shall have a luminous image projected on a black ground. For illuminating the object, an argand lamp is placed near the center of the lantern, the light of which is concentrated upon the object in two ways; first, by means of a thick lens, usually plano-convex, so situated between the lamp and the object that the rays which diverge from the lamp shall be collected and condensed upon the object; and secondly, by means of a concave reflector situated behind the lamp, which serves a similar purpose.

Why is it necessary to illuminate the object? Describe the Magic Lantern,—its different parts. Where is the magnifying lens placed? Where the illuminating glass?

Fig. 127.



A, the magnifying lens.

B, the object introduced through an opening in the tube.

C, the condensing lens.

D, the lamp.

E, the concave mirror.

F, the image thrown on a screen, or a white wall, in a dark room.

a, a thumb-piece, by which the magnifier may be made to approach or to recede from the object, and thus the image be thrown to a greater or less distance, according to the magnitude required. As the image is inverted with respect to the object, it is only necessary to introduce the object itself in an inverted position, and the image will be erect.

The objects employed in the Magic Lantern are very various, consisting of figures of men and animals; of caricatures; of representations of the passions; of landscapes; and of astronomical diagrams. When the last are employed, this apparatus becomes subservient to a useful purpose in teaching astronomy, and is frequently so employed by popular lecturers on that subject.

545. The Solar Microscope does not differ in principle from the Magic Lantern, only the object is illuminated by the concentrated light of the *sun* instead of that of a lamp. And since a powerful illumination may thus be effected upon minute objects placed before a magnifier of great power, the solar microscope is usually employed to form very enlarged images of the most minute substances, as the smallest insects, the most delicate parts of plants, and other attenuated objects of natural history. For magnifiers, several of different focal distances are employed, varying from an inch to the $\frac{1}{10}$ or $\frac{1}{20}$ of an inch, it being understood, that those of the shortest focus and greatest magnifying powers can be used only for the minutest objects, since, when bodies of a larger size are brought so near

Describe from the figure. What objects are used for the Magic Lantern? *Solar Microscope.*—How does it differ from the Magic Lantern? What is the size of objects usually employed in this instrument? What are the usual focal distances of the lenses?

a small lens, their light strikes the lens too obliquely to be transmitted through it. The magnifying lens is fixed into the mouth of a tube, and the object placed near its focus, much in the same manner as in the magic lantern; but instead of the body of the lantern (which contains the illuminating apparatus) a mirror, about three or four inches wide, and from twelve to eighteen inches long, is attached to the other end of the tube. This mirror is thrust through an opening in the window shutter of a dark room, and the mouth of the tube to which it is fixed is secured firmly to the shutter, so that the mirror is on the outside, and the tube with its lenses is on the inside of the shutter. By means of adjusting screws, the mirror is turned in such a way as to direct the sun's rays into the tube, where they are received by one or more of the lenses, called *condensers*, which collect them and concentrate them upon the object, which thus becomes highly illuminated, and capable of affording an image sufficiently bright and distinct, though magnified many thousands or even millions of times. It will be observed, that the magnitude of the image depends here, as in other cases of the simple microscope, upon the ratio between the distances of the object and the image from the center of the magnifier. If, for example, the object be within the tenth of an inch of the lens, and the image be thirty feet, or three hundred and sixty inches from it, then the image will be $360 \times 10 = 3600$ times as large as the object in diameter, and $(3600)^2 = 12,960,000$ times in surface. With a given lens, the size of the image depends wholly on the distance to which it is thrown; that is, on the distance of the wall or screen where it is formed.*

546. When the solar microscope is well constructed, it affords the most wonderful results, and greatly enlarges our conceptions of the delicacy, perfection, and subtility of the works of nature. In inspecting *vegetables*, the eye is delighted with the regularity and beauty which characterizes the texture and intricate structure of plants and flowers. The most delicate fibres of a leaf, the pores through which the vegetable fluids circulate, the downy covering of plants and foliage, as of cer-

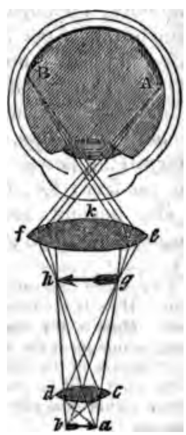
Explain the use of the mirror that is attached to the solar microscope—also the condensers. Upon what does the magnitude of the image depend? Suppose the object to be 1-10 inch from the lens, and the image be formed at the distance of thirty feet, what will be the magnifying power? What substitute for the sun's light is employed in the oxy-hydrogen microscope? What appearances are presented under the microscope by vegetable substances?

* *Instead* of employing the sun to illuminate objects, the intense light produced by *the combustion* of a jet of oxygen and hydrogen gases, is now used with great effect. *Whence the* instrument is called the *oxy-hydrogen* microscope. The light of the jet is *reflected* on the object by means of a concave speculum.

tain mosses, which is too minute to disclose its figure to the naked eye,—objects of this kind, when expanded under the solar microscope, astonish and delight us by the symmetry of their structure. Their appropriate *colors* are not so well exhibited by this instrument, as by some other forms of the microscope to be described hereafter. In the *animal* kingdom, the solar microscope extends the range of vision in a manner no less surprising and instructive. The minutest insects we are acquainted with, are exhibited to us as animals of the largest size, and often of monstrous shapes, from the multiplicity of their parts and apparent disproportion; and animalcules, or those members of the animal creation which are too minute to be seen at all by the naked eye, are suddenly brought into life in countless numbers. The forms, the motions, and the habits of these beings, are among the most curious revelations of the solar microscope. The *circulation of the blood* may be seen in the fins of fishes and other transparent parts of animals, presenting a very curious and interesting spectacle. The *crystallization of salts*, which may be exhibited while the crystals are forming and arranging themselves, (as many of them do with great precision and symmetry,) is among the finest representations of this instrument.

Since the light is transmitted through the objects, it will of course be understood, that only such objects as are *transparent* can be employed in the manner already described. In some varieties of the solar microscope, there are special contrivances for exhibiting *opake* objects by means of reflected light.

Fig 128.



547. When we form an image of an object with the single microscope, (as is done in the magic lantern and solar microscope,) if that image is not too large, we may obviously apply it to a magnifier as we would to an original object of the same size. This is the principle of the Compound Microscope.

The COMPOUND MICROSCOPE consists of at least two convex lenses, one of which, called the *object-glass*, is used to form an enlarged image of the object, and the other,

Does this instrument give a good representation of the colors of objects? Describe the appearances of animal objects, of the circulation of the blood, and of the crystallization of salts. Are the objects usually *employed* transparent or opake? How may opake objects be illuminated?

called the *eye-glass*, is used to magnify the image still farther.

Thus, let *ab*, (Fig. 128.) be the object, being placed a little farther from the object-glass, *cd*, than the principal focus, the rays of light emanating from it will be collected on the other side of the lens and form an image, *gh*, whose diameter is as much larger than that of the object as its distance from the lens is greater. (Art. 502.) Let *ef* be the eye-glass, which must be placed at such a distance from the image, that the latter shall be in the focus of parallel rays; then the rays proceeding from the image will go out parallel,* and come to the eye, situated behind the glass, in a state favorable for distinct vision.

548. The *magnifying* power of the Compound Microscope is estimated as follows. First, the diameter of the image will be to that of the object as their respective distances from the lens. Secondly, the image is magnified by the eye-glass according to the principles of the single microscope, (Art. 536.) namely, from the ratio of its focal distance to the limit of distinct vision. Thus, suppose the image is formed at ten times the distance of the object; it will of course be magnified ten times. Again, suppose the eye-glass has a focal distance of one inch, the limit of distinct vision being five inches; the image will be farther magnified five times; by both glasses, therefore, the object will be magnified fifty times. If the first ratio be that of one to one hundred, then the instrument will magnify the linear dimensions five hundred times, and the surface two hundred and fifty thousand times. From this double magnifying process, it might be supposed that, by means of the compound microscope, it would be easy to attain a much higher magnifying power than by the single microscope; but this is not the fact; for, in the first place, we cannot form an image of a size beyond certain moderate limits, without making it too large for the eye glass to cover; or, if an eye-glass of very

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Compound Microscope.—State its principles. Describe its construction. How is the magnifying power of the compound microscope estimated? How is the diameter of the image to that of the object? Upon what principle is the image magnified? Suppose the image has ten times the distance of the object, and the eye-glass has a focal distance of one inch, what will be the whole magnifying power? Why can we not attain a higher magnifying power by the compound than by the single microscope?

* It is to be remarked here and in all similar cases, that it is only the rays of *each individual pencil* that are parallel; that is, those rays which come from the same point in the object. The rays of different pencils may cross each other variously, and the different pencils may converge or diverge among themselves; still, if the rays of each pencil be parallel to one another, the vision will be distinct.

large field of view be employed, its focal distance must be great, and consequently its magnifying power small. We are, therefore, unable to employ so high a magnifier for our object-glass as we may apply to the naked eye, and we can employ only a microscope of still inferior power for our eye-glass.

549. On account of the necessity of using a large eye-glass to view the magnified image, compound microscopes require to have the tube which contains the glasses, larger towards the eye-glass than towards the object-glass. Although the compound does not possess higher magnifying powers than the simple microscope, yet it commands a much greater field of view. We view the image with the eye-glass in the same manner as we view the object with a single microscope; but having already a magnified representation of the object, we have no occasion to apply to the eye so high a magnifier, and therefore we may employ one of greater focal distance which consequently takes in a greater field of view. The field of view is still farther improved in some compound microscopes by interposing a *field glass*, which is a convex lens introduced between the eye-glass and the place of the image, and near the latter (as a little above *gh*, Fig. 128,) the effect of which is to diminish the divergency of the pencils of rays, and thus to bring into the range of the eye-glass those pencils which would otherwise diverge too much to fall within it. It has been before remarked that the cornea performs a similar office for the crystalline lens of the eye. (Art. 526.)

550. The Portable Camera Obscura, which is used chiefly for delineating landscapes, consists of a wooden box, (answering to the dark chamber, Art. 523.) with which is connected a convex lens, so exposed to the landscape as to receive the rays of light from the various objects in it, and form a picture of them on a screen placed within the box at the focal distance of the lens. Such is a general description of the instrument, of which there are several different forms. The following diagram represents a convenient form.

ABCD, a box usually made of thin pieces of mahogany.

a d, a plano-convex lens, this form being preferred because it has less aberration than a double convex.

What rays are rendered parallel to each other? What shape has the tube of a compound microscope? Why has it a greater field of view than the single microscope? What is the field glass? Describe the Portable Camera Obscura. For what purpose is it used?

Fig. 129.

ED, a plane mirror, turning on a hinge at D, and capable of being raised or lowered, so as to admit more or less of the landscape.

b c, a piece of pasteboard, covered with a sheet of fine white paper, and bent so as to form a concave screen, and placed at the focal distance of the lens. A casting of stucco, of the figure of a concave portion of a sphere affords the most perfect picture.

The rays of light from external objects, falling upon the mirror ED, are conveyed to the lens in the same manner as though they came directly from external objects at the same distance behind the mirror. Passing through the lens, they are brought to a focus and form a picture of the landscape on the screen, which may be viewed by an opening in the side of the box at F, and may be copied by a hand introduced into the box by an opening below.

Although the image is inverted with respect to the objects, yet as the spectator, in looking into the box, stands with his back to the landscape, the picture appears erect.

CHAPTER VI.

OF TELESCOPES.

551. *The Telescope is an optical instrument, designed to aid the eye in viewing distant objects.*

The construction of this noblest of instruments, in its different forms, involves the application of all the leading principles of the science of Optics. The study of the Telescope is therefore the study of the science, and a distinct enunciation of

Explain the manner in which the image is formed. Why does not the image appear inverted? *Telescopes.*—Define the telescope.—What is said of the study of it?

the principles involved in it, will serve as a recapitulation of the most useful principles of Optics. The advantage which the student will derive from reviewing these points, as exemplified in their application, will justify us in bringing up distinctly to view various principles already unfolded.

552. The leading principle of the Telescope may be thus enunciated:

By means of either a convex lens, or a concave mirror, an image of the object is formed, which is viewed and magnified with a microscope.

The most general division of the instrument is into Refracting and Reflecting Telescopes; of which the former produce their image by means of a convex lens, and the latter by means of a concave mirror. The instrument, according to the uses to which it is applied, receives the farther denominations of the Astronomical and the Terrestrial Telescope; and also Telescopes are named, after their several inventors, Galileo's, Newton's, Gregory's, Herschel's, &c.

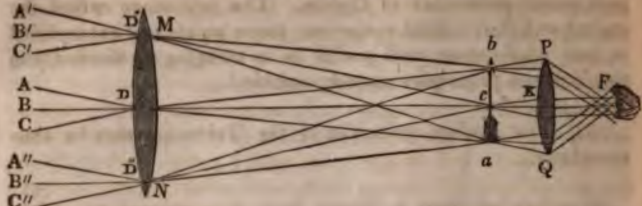
The Astronomical Telescope.

553. We begin with this variety because it is one of the most simple, and because, in connexion with it, we may conveniently study the theory of the instrument at large.

The Astronomical Telescope has essentially but two glasses: these are usually fixed in a tube of brass, one at one end, and the other at the other end. The glass at the end of the tube which is directed to the object is called the *object-glass*, and that at the end to which the eye is applied, is called the *eye-glass*. The object-glass is a convex lens which forms an image of a distant object, as a star, in its focus of parallel rays, and the eye-glass is a microscope with which we view the image, at a distance equal to its focus of parallel rays. Of course, the distance of the two glasses from each other is equal to the sum of their focal distances. See the annexed figure.

Enunciate it leading principle. What are the two principal kinds? Specify the different sorts of telescopes. *Astronomical Telescope.*—How many glasses has it? What is the object-glass, and what the eye-glass? What office does each perform?

Fig. 124.



MN, object-glass.

PQ, eye-glass.

A'D', AD, A''D'', parallel rays from the top of the object.

B'D', BD, B''D'', " " " center ditto.

C'D', CD, C''D'', " " " bottom ditto.

ba, inverted image formed in the focus of parallel rays.

*b*PF, a pencil of rays, proceeding from the top of the image to the eye-glass and rendered parallel.

*c*KF, a similar pencil from the center.

*a*QF, ditto the bottom.

F, point where the different pencils cross the axis.

554. In this instrument we observe a striking resemblance to theCompound Microscope. (Fig. 128.) In the microscope, however, since the object is nearer ths lens than the image, the image is greater than the object; but in the telescope, since the object is removed to a great distance, the image is formed much nearer to the lens than the object, and is proportionally smaller. Hence, Compound Microscopes have their tubes enlarged in diameter towards the eye-glass, while telescopes have their tubes diminished in that direction. Since the vertical angles at D, subtended on the one side by the object, and on the other by the image, are equal, were the eye situated at the center of the object-glass, it would see the object and the image under the same visual angle, and consequently, both would appear of the same magnitude. Moreover, were the eye placed at the same distance from the image on the other side of it, it would be apparently of the same size as before, and therefore of the same apparent diameter as the object. But by means of a mic-

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Describe by the figure. Point out how it resembles the compound microscope, and how it differs from it. Why have compound microscopes their tubes enlarged, and telescopes their tubes diminished towards the eye-glass? Were the eye situated at the center of the object-glass, *how would* it see the object and the image? Explain how it magnifies?

roscope, such as the eye-glass in fact is, we may view it at a much nearer distance, and of course magnify it to any extent, as was fully shown in explaining the principles of the simple microscope. (Art. 536.) Hence the magnifying power of the telescope depends on the ratio between the focal distances of the object-glass and the eye-glass. If, as in the figure, the common focus is ten times nearer the eye-glass than to the object-glass, the instrument will magnify ten times; if one hundred times nearer, one hundred times; and so in all other cases. Hence we may increase the magnifying power of the instrument, either by employing an object-glass of a very small curvature, which throws its image to a great distance, or an eye-glass of high curvature and small focal distance. Suppose, for example, the object glass has a focal distance of forty feet, or four hundred and eighty inches, and the eye-glass has a focal distance of one tenth of an inch, then the magnifying power of this instrument would be four thousand and eight hundred in diameter, and the square of this number in surface.

555. As the sphericity of the eye glass may be increased indefinitely, and its focal distance diminished to the same extent, it would seem possible to apply very high magnifying powers in very short telescopes. For example, suppose the focal distance of the object glass is twenty-four inches; by using a microscope of $\frac{1}{10}$ of an inch focus, we have a power of two hundred and forty. But it must be kept in mind, that such microscopes command only an exceedingly small field of view, and would, therefore, not enable us to see any thing more than a minute portion of an object of any considerable size; and not sufficient light would be transmitted through such an aperture to answer the purpose of vision.

Since the image is inverted with respect to the object, and is viewed in this situation by the eye-glass, objects seen through Astronomical Telescopes appear inverted. By the addition of several more lenses, they may be made to appear erect, as will be shown in the description of the Day Glass, or Terrestrial Telescope; but at every new refraction a certain portion of light is extinguished, a loss which it is important to avoid in instruments designed to be used at night; while, in regard to

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On what ratio does the magnifying power depend? How may we increase the magnifying power? What would it be, when the object-glass has a focal distance of 40 feet, and the eye-glass a focal distance of 1-10 inch? Why can we not apply high magnifiers in very short telescopes? Are objects seen by astronomical telescopes erect or inverted? Why is it not made erect by introducing additional lenses?

celestial objects, it is not essential whether they are seen erect or inverted. The place for the eye to view the image with the best advantage is at F, where the pencils of parallel rays meet.

556. The *difficulties* to be overcome in the construction of a perfect Refracting Telescope, (some of which are very formidable,) are chiefly the following: 1. Spherical aberration; 2. Chromatic aberration; 3. Want of sufficient light; 4. Want of a field of view sufficiently ample; 5. Imperfections of glass. Each of these particulars we will briefly consider.

557. *Spherical aberration*, it will be recollected, occasions indistinctness in images formed by lenses, in consequence of the different rays of the same pencil not being all brought to a focus at the same point, those which fall upon the extreme parts of the lens being more refracted and coming to a focus sooner than those which are nearer to the axis. (See Art. 503.) The amount of this error is found to depend on two circumstances, namely, the diameter of the lens, or what is technically called its *aperture*, and its focal distance, increasing rapidly as the aperture is increased, and diminishing as the focal distance is increased. *Small apertures and flat or thin lenses are, therefore, most free from spherical aberration.* But if we use small apertures we cannot have a strong light, which is a circumstance of the greatest importance in astronomical observations, since it is of little consequence to enlarge the dimensions of an object if we have not light enough to render it visible. Indeed, many astronomical objects, as small stars, are rendered visible by the telescope, not in consequence of any apparent increase of size, but because this instrument collects and conveys to the eye a much larger beam of light from them than would otherwise enter it. While the diameter of the beam which falls upon the naked eye is only the fraction of an inch, that collected by the telescope may be several inches, or even several feet, according to the size of the instrument. Hence, the advantage of large apertures is obvious. Again, we cannot wholly remedy the error in question, though we may diminish it by using very flat lenses which have great focal distances; but the tendency of this expedient is to render the instrument inconveniently long. Other

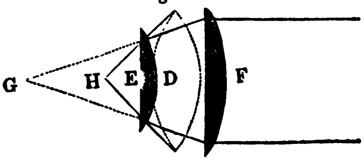
State the difficulties to be overcome. *Spherical aberration*—what is it? On what two circumstances does it depend? What kind of apertures and lenses are most free from it? What inconvenience attends the use of such apertures? What is the inconvenience of using very flat lenses?

expedients, therefore, become necessary for correcting spherical aberration in refracting telescopes.

558. In the eye-glasses, which are liable to the same difficulty, where the lens has a great curvature, as is the case with such as have high magnifying powers, the aperture is necessarily reduced very much, by excluding all the light except what passes through the central parts of the lens. At least this is the case where glass lenses are used. But the microscopes made of diamond, sapphire, and other gems, have not only high refractive powers, but are less subject to spherical aberration than similar lenses of glass.

But although eye pieces, on account of their small size, may sometimes be made of the precious gems, yet this can rarely be the case on account of the great expense attending them. It is obvious also that they cannot be employed for the object lenses. The most successful method of diminishing spherical aberration in eye pieces of glass, is by a combination of plano-convex lenses, by means of which a given refracting power may be attained with far greater distinctness than by a single lens of the same power. Thus, when two plano-convex lenses are placed as in Fig. 131, it is found that the image has four times the distinctness of a double convex lens of equivalent power.* Here F is a lens which would bring the parallel rays to a focus and form the image at the distance of G; but E is another similar lens, which receiving them in a converging state, makes them converge more and come to a focus at H. The double convex lens D would do the same, but with much greater spherical aberration. It appears, indeed, that the spherical aberration may be wholly removed by combining a meniscus with a double convex lens of certain curvatures.

Fig. 131.



559. In object-glasses, which, on account of their small curvatures, are not so subject to error from spherical aberration as

What advantages have eye pieces made of diamond, sapphire, &c.? How is spherical aberration diminished in eye pieces of glass? Illustrate by the figure.

* *The Scioptic Ball* used in the camera obscura, (Art. 524.) is formed of two such lenses.

eye-glasses are, the most advantageous form is that of a double convex lens of unequal curvatures, the radii of the opposite surfaces being as one to six, (Art. 504.) and the flat side being turned towards the parallel rays.

In short, it appears, that in order to avoid the errors arising from spherical aberration, in large lenses, they must be made as thin as convenience will permit; that where it is practicable, they may be most advantageously formed of the precious gems, particularly the diamond; that a plano-convex lens with its convex side towards the parallel rays has less aberration than a double convex lens of equivalent power; that two plano-convex lenses may be so combined as to have only one fourth as much aberration as the double lens, and a meniscus may be so united to a double convex lens as wholly to prevent aberration; and finally, that the aberration may be reduced to a very small error simply by employing a double convex lens whose curvatures on the opposite sides are as 1 to 6.

Since lenses having the curvature of one of the conic sections are free from spherical aberration, Sir Isaac Newton ground an object glass into the figure of a paraboloid. This was free from the error in question, but involved another still more formidable, since it decomposed the light and gave an image tinged with the colors of the rainbow. On observing this, Sir Isaac pronounced the farther improvement of the *refracting* telescope to be hopeless, and betook himself to exclusive efforts for improving the *reflecting* telescope. But the combined ingenuity of philosophers and artists has nearly overcome this error also.

560. The next difficulty, therefore, to be considered, is that which arises from the separation of the prismatic colors, in consequence of the different refrangibility of the different rays, an error which is called *Chromatic Aberration.*

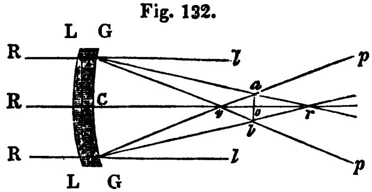
The general principles of Chromatic Aberration, will be readily comprehended by calling to mind, that distinct images are formed only when the rays of the same pencil which flow from any point in the object are collected into one and the same point in the image, unmixed with rays from any other point; that the prismatic rays which compose white light have severally different degrees of refrangibility, some being more turned out of their course than others, in passing through the same

What is the most advantageous form of object-glasses? State the several expedients for avoiding the errors of spherical aberration. Why may not lenses of a parabolic figure be used? Chromatic *aberration. Explain* what it is.

medium; that, consequently, the different colored rays of the same pencil would meet in different points, each set of colored rays forming its own image, but all these images becoming blended with one another, would thus compose a confused, colored picture.

To illustrate these principles let LL be a lens of crown glass, and RL, RL, rays of white light incident upon it, parallel to its axis Rr. Let the extreme *violet* rays be refracted so as to meet the axis, in v; then the extreme *red* will meet the axis at some point more distant from the lens, as at r. Cv and Cr are the focal distances of the lens for the violet and the red rays respectively. The distance vr is the chromatic aberration, and the circle whose diameter is ab, which passes through the focus of the mean refrangible rays at o, is called the *circle of least aberration.*

Fig. 132.



561. It is clear from these observations, that the lens will form a violet image of the sun at v, a red image at r, and images of the other colors of the spectrum at intermediate points between r and v; so that if we place the eye behind these images we shall see a confused image, possessing none of that sharpness and distinctness which it would have had if formed only by one kind of rays.

The separation of white light into its prismatic colors, is called *Dispersion*; and the comparative power of effecting this separation possessed by different media, is called the *Dispersive power.* The dispersive power is measured by the ratio which, in any case, the separation of the red and violet rays bears to the mean refraction of the compound ray. Thus, if a ray of solar light on passing through a lens, is turned out of its origional direction 27°, and the red and violet rays are separated from each other 1°, then the dispersive power is said to be $\frac{1}{27}$, which is usually expressed in the form of a decimal fraction, $.037=\frac{1}{27}$.

562. *Different bodies possess different dispersive powers.*

The dispersive powers of a few of the most important substances in relation to the subject before us, are exhibited in the following table.

Illustrate by the figure. Define Dispersion, and Dispersive Power. What is meant by saying that the dispersive power is 1-27th?

	Dispersive Power.		Dis. Power.
Oil of Cassia,	0.139	Plate Glass,	0.032
Sulphuret of Carbon,	0.130	Sulphuric Acid,	0.031
Oil of Bitter Almonds,	0.079	Alcohol,	0.029
Flint Glass,	0.052	Rock Crystal,	0.026
Muriatic Acid,	0.043	Blue Sapphire,	0.026
Diamond,	0.038	Fluor Spar,	0.022
Crown Glass, (green,)	0.036		

From this table it appears, that the transparent substances which have the highest dispersive power, are the oil of cassia and the sulphuret of carbon,* both of which fluids have been made to perform an important service in the construction of achromatic telescopes; that flint glass, as that used for decanters, has a much higher dispersive power than crown glass, or that which is analogous to window glass; that the diamond has a low dispersive power, but is exceeded in this by rock crystal, the sapphire, and flour spar, which last bodies have the least dispersive power of any known substances.

563. With these facts in view, we may now inquire *by what means the object glass of the telescope is rendered achromatic.*

If we place behind LL (Fig. 132.) a concave lens GG of the same glass, and having its surfaces ground to the same curvature, such a lens having properties directly opposite to those of the convex lens, will neutralize its effects. Consequently, the rays which were separated into their prismatic colors by the convex lens will be reunited by the concave lens, and reproduce white light. But though such a combination of the two lenses will correct the color, yet it also destroys the power of the convex lens to form an image, on which its use solely depends. Could we find a concave lens which would correct all the color and yet not destroy this refracting power, the two lenses would evidently form the achromatic combination sought for. Now this is what is actually done: by making the concave lens of a substance which has a *higher dispersive power* than than that of which the convex lens is made, the curvature of the concave lens will not need to be so great as that of the convex lens, and of course the two together, constituting the compound lens, will be equivalent in refracting power to a single lens,

What bodies have the greatest dispersive powers? What the least? By what means is the object glass of the telescope rendered achromatic? State the combination of two lenses, so as to destroy the chromatic effect *but leave* a refracting power.

* A limpid fluid prepared from sulphur and charcoal.

whose convexity is equal to the difference of their curvatures. The most common combination is that of flint glass with crown glass, the concave lens being made of flint glass, and the convex of crown. By the table in Art. 562, it will be seen that the dispersive power of flint glass is 52 while that of crown glass is 36, which numbers are nearly as 3 to 2, and these numbers, therefore, may be employed for the sake of illustration. Since the power of the concave lens to reunite the prismatic rays is so much greater than that of the convex lens to separate them, we shall not require a refractive power to effect this equivalent to that of the convex lens; that is, a concave lens of less curvature and proportionally greater focal distance, will serve our purpose. Therefore,

An achromatic lens is formed by the union of a convex and a concave lens, whose dispersive powers are respectively proportional to their focal distances.

564. A telescope furnished with an object glass thus formed, is called an *Achromatic Telescope*. The spherical aberration being corrected by the methods pointed out in Art. 557, and the chromatic aberration being destroyed in the manner above described, the Refracting Telescope becomes an instrument of great perfection, and is reckoned among the greatest works of art. Until recently, it was rare to meet with Refracting Telescopes of an aperture of more than from three to five inches; for we have already seen that the errors of spherical and chromatic aberration increase rapidly as the size of the aperture is augmented.

565. If it be asked, what is the *use* of a large aperture, since the magnifying power does not depend upon the diameter of the object-glass, but upon the ratio between the focal distance of the object-glass and the focal distance of the eye-glass, (Art. 554.) we answer, that the use of a large aperture is to admit, condense, and finally convey to the eye, a larger beam of light, and thus to render many objects, as the smaller stars, or Jupiter's belts, visible, which otherwise would not be so, on account of the feebleness of the light which they transmit to us. *Want of light* is in fact one of the greatest difficulties that the telescope has to contend with; for, in the first place, the object-glasses of most telescopes are comparatively small, and are necessarily

Of what substances are the two lenses made? State the proposition. *What is said of the* perfection of the achromatic telescope? What is the *use of a large aperture?* What is said of *want of light*?

so on accoont of the difficulty of procuring suitable glass for those of a larger size ; and in the second place, of the light admitted through the object-glass, a great proportion is intercepted and wasted in various ways, many instruments being able to save only the central rays without rendering the image indistinct and colored. Thus, when very high magnifiers are applied, (which of course have very small focal distances,) the rays proceed from the focus and fall upon the microscope so obliquely, that only those which pass through the central parts of the lens can be saved, since such as fall upon the marginal parts of the lens are too much affected by spherical and chromatic aberration, to form with the others a distinct and colorless image.

566. *Want of field of view* is another difficulty to be surmounted. When we use an object-glass of short focus with a high magnifier, the microscope must have a focus proportionally short, and of course the field of view will be very limited and the light but feeble. This difficulty may be obviated by using an object-glass of very great focal distance. If, for example, the focal distance of the object-glass were only 12 inches, in order to attain a magnifying power of 120, we must employ a microscope whose focal distance is only $\frac{1}{10}$th of an inch. But if the focal distance of the object-glass were 10 feet, or 120 inches, then our microscope might have a focal distance of 1 inch, which would give a larger field and a stronger light. With the view of obviating several of the foregoing difficulties, the earlier astronomers who used the telescope, employed for their object-glasses lenses whose focal lengths were very great. Cassini, a French astronomer, constructed telescopes eighty, one hundred, and one hundred and thirty-six feet long ; and Huygens employed such as were nearly the same length. The latter astronomer dispensed with the tube, fixing his object-glass, contained in a short tube, to the top of a high pole, and forming the image in the air near the level of the eye, which image he viewed with an eye-glass, as usual. With telescopes of this description, several of the satellites of Saturn were discovered.

567. But one of the most formidable difficulties hitherto encountered in the construction of large Refracting Telescopes, has arisen from the *imperfections of glass*. When Dollond (the English artist who first perfected the Achromatic Telescope,)

Why are very high magnifiers attended with a want of light? What is said of *want of field*? What advantage have very long telescopes? *How long* have they sometimes been made? What is said of the *imperfections of glass*?

engaged in the manufacture of his instruments, he fortunately had possession of a considerable quantity of very fine glass; but when that was used up, no more of equal quality could be obtained in England.* On the continent, however, one or two celebrated artists have been more successful. The most distinguished manufacturer of optical glass was M. Guinand of Switzerland, who died in 1823. He greatly excelled all his predecessors or cotemporaries in fabricating large masses of perfectly homogeneous glass. But even he could produce disks of twelve or eighteen inches in diameter in no other way, than by selecting the purest specimens of smaller pieces, and joining them together. In 1805, M. Fraunhofer of Bavaria, a celebrated manufacturer of telescopes, invited Guinand to become his associate in the manufacture of optical glass; and from the united efforts of these most ingenious men, proceeded glass of unexampled transparency and purity. Fraunhofer has recently deceased, and the difficulty of procuring perfect glass is renewed. This induced the Royal Society of London to appoint a committee to institute new experiments on this subject. These have been prosecuted with the greatest ability, but have as yet produced no important results.

568. These circumstances we have thought worthy of being recited in order to impress on the mind of the learner the formidable nature, as well as the great number, of the difficulties to be overcome in the construction of a large Achromatic Telescope. Yet they have in several instances, been completely surmounted. Fraunhofer executed two telescopes with achromatic object-glasses, the one nine inches and nine tenths, and the other twelve inches in diameter; and at the period of his death, he was proposing to undertake one eighteen inches in diameter. That of 9.9 inches aperture was made for the Russian government, for the use of the observatory at Dorpat, where under the direction of M. Struve, a distinguished astronomer, it has already achieved several valuable discoveries in astronomy. The object-glass has a focal length of twenty-five feet. The concave part of the compound lens is formed of a dense flint glass made by Guinand, and has a greater dispersive power than any obtained before. It is perfectly free from veins, and

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Who has made the best glass? What is said of Fraunhofer? What is said of the size and quality of the Dorpat telescope?

* The present Mr. Dollond, a successor of the inventor of Achromatic Telescopes, "has not been able to obtain a disk of flint glass four inches and a half in diameter, fit for a telescope, within the last five years, or a similar disk of five inches diameter within the last ten years".—*Faraday*, Phil. Trans. 1830.

nearly from every impurity. The instrument has four eye-glasses varying in magnifying power from one hundred and seventy-five to seven hundred.*

569. The great difficulty of procuring perfect glass for achromatic telescopes has led opticians to attempt the construction of lenses for this purpose out of some transparent fluid which might be inclosed in thin glass. Such a medium seemed peculiarly suited to take the place of the concave lens in which the principle difficulty resides. Professor Barlow, of the Military Academy at Woolwich, has recently made several telescopes on this principle, the last of which had an aperture of 7.8 inches, and performed as well as the larger kinds of achromatic telescopes constructed in the usual way. The fluid employed for this purpose was the sulphuret of carbon, a limpid fluid prepared from sulphur and charcoal. It is singularly adapted to optical purposes, having a refracting power about equal to that of the best flint glass, with a dispersive power more than double that of the same substance. It is, moreover, perfectly colorless, beautifully transparent, and although it is very volatile yet when closely sealed it possesses nearly the same optical properties under all required temperatures. The advantages of using sulphuret of carbon, should the experiments finally succeed as well as is expected, are the following:

1. It renders us independent of flint glass.
2. It enables us to increase the aperture of the telescope to a very considerable extent.
3. It gives us all the light, field and focal power of a telescope of one and a half times at least, probably twice the length of the tube.
4. The expense of large telescopes (which consists mainly in the cost of the object-glass) is greatly diminished, the most expensive part being supplied with less than one ounce of sulphuret of carbon of the value of three shillings.

The Terrestrial or Day Telescope.

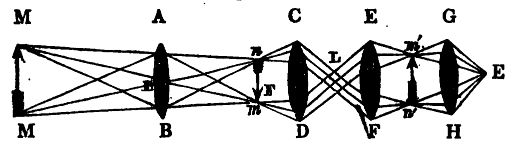
570. As the Astronomical Telescope represents objects inverted, it requires to be so modified for terrestrial views, that

What are its magnifying powers? What is said of *fluid* object-glasses? Recite Professor Barlow's experiments. What was the size and performance of his telescopes? What advantages have fluid object-lenses over those of glass?

* It is said that as a general rule, Achromatic Telescopes are priced in the ratio of the *cube* of the aperture. If a telescope with an object glass three inches in diameter is valued at five hundred dollars, one of twelve inches would cost sixty-four times as much, that is, thirty-two thousand dollars.

objects may appear erect. This is effected by the addition of two more lenses of similar figure to that of the eye-glass, and of the same focal length. The first of these additional glasses forms a second image of the object inverted with respect to the first image and therefore erect with respect to the object. This image is viewed by the second glass as by a simple microscope. Thus, AB, the object glass forms an inverted image *nm* of the

Fig. 133.



object MM. Instead of viewing this image by the eye placed at L, as in the common astronomical telescope, we suffer the pencils of parallel rays to cross each other at L and fall upon a second lens EF (similar in all respects to CD) which collects them into an image *m'n'* in its focus of parallel rays, which image is viewed by the eye glass GH in the same manner as the object itself would be.

As some portion of the light is reflected, and some absorbed and dissipated by passing through these additional lenses, they of course diminish the brightness of the view; but in the day time there will usually be light enough for distinct vision after this loss is sustained, while it is more agreeable and convenient to have the objects presented to us in their natural positions than inverted. It will be remarked that the additional lenses do not magnify, the focal length of each being the same as that of the first eye-glass. Were they rendered smaller for the purpose of magnifying, the field of view and the light would both be impaired.

571. We usually find in telescopes, particularly those designed for terrestrial objects, some contrivance, as a draw tube, by which the eye-glass can be brought near to, or withdrawn from the object-glass. This is to accommodate the instrument to objects at different distances. When it is directed to very near objects, the image is thrown farther back, and therefore in order that it may be in the focus of the eye-glass, (which is essential to

Day Glass.—How does it represent objects? By what means is this effected? Describe the construction by the figure. What effect have the additional glasses upon the brightness of the image? Do these magnify? *What is the use of the draw tube?*

distinct vision) the latter must be drawn backward; but where the object is remote, the image is formed nearer to the object-glass, and then the eye-glass must be moved forward, till its focus of parallel rays, comes to the place of the image. For a similar reason, near sighted persons require the eye-glass to be brought nearer than usual to the object-glass; for then the image will be nearer to the eye-glass than its focus of parallel rays, and the rays will meet the eye diverging, a condition favorable to eyes naturally too convex. For a contrary reason, long sighted persons, who usually wear convex spectacles, may adjust the telescope to suit their eyes without spectacles, by removing the eye-glass farther back than usual.

Most terrestrial telescopes contain a greater number of glasses than are represented in Fig. 133. Such a number are used for the purpose of correcting spherical and chromatic aberration, these errors being less in several flat and thin lenses than in a smaller mumber of equivalent lenses of greater curvature.

Astronomical telescopes are easily adapted to terrestrial observations, by removing the eye-glass and substituting a tube containing the additional glasses for rendering the view erect.

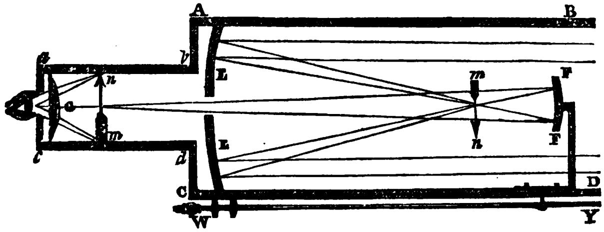
Reflecting Telescopes.

572. Reflecting Telescopes differ in principle from those already described only in forming their image by a *concave reflector*, instead of a convex object-glass. The most common form of the Reflecting Telescope, is the *Gregorian*, so called from the inventor, Dr. James Gregory of Scotland. The general principles of this instrument may be explained as follows:

In the Gregorian Telescope, the light (supposed to come in parallel rays) is first received by a large concave speculum, by which it is brought to a focus and made to form an inverted image. On the opposite side of this image, and facing the large speculum, is placed a small concave speculum, of greater curvature, at such a distance from the image that the rays proceeding from it and falling on the speculum are made to converge to a focus situated a small distance behind the large speculum, passing through a circular aperture in the center of it. This second image is magnified by a microscope as in the Refracting Telescope. This description may now be applied to the annexed figure.

What is the use of the glasses sometimes employed in addition to those required to make the image erect? How may astronomical telescopes be adapted to terrestrial observations? *Reflecting Telescopes.*—How *do they form* the image? In the Gregorian telescope, how is the image *formed?* State how this, by a second reflexion, is conveyed to the eye?

Fig. 134.



ABCD, a large tube of brass, iron, or mahogany to contain the reflectors.

abcd, a smaller tube to receive the second image and the eye glass.

EE, large concave speculum, usually composed of a metallic compound called *speculum metal.*

FF, small concave speculum.

mn, image formed by the large reflector.

nm, image formed by the small reflector.

G, eye-glass.

WY, a metallic rod having a screw connected with the small reflector, by means of which this reflector is made to approach the first image or to recede from it.

Some of the pencils of rays necessary to form the respective images, are omitted in the figure to prevent confusion.

573. From the foregoing construction it is evident, first, that the image viewed by the eye being in the same position with the object, the latter will appear *erect;* secondly, that since the mirrors may be formed of a parabolic figure,* all *spherical aberration* may be easily prevented; thirdly, that since light is not decomposed by reflexion, reflecting telescopes are not subject to *chromatic aberration;* and, hence, that is not necessary to lengthen the tube as the aperture is increased, as is the case in refracting telescopes; (Art. 566.) but since the light will depend, chiefly, on the size of the large reflector, a strong light may be obtained with a comparatively short tube. The achromatic telescope, however, with all the latest improvements, is deemed a more perfect and more convenient instrument than the reflect-

Describe from the figure. Does the Gregorian telescopes give the image erect or inverted? How is spherical and chromatic aberration prevented? How do the Achromatic and Reflecting telescopes compare in perfection?

* An elliptical figure has the same property.

ing telescope; and it is supposed that there will be no occasion hereafter to construct reflectors of such enormous dimensions as those of Dr. Herschel. Some account of his forty feet reflector may form a suitable close to this sketch of optical instruments.

474. Under the munificient patronage of George III, Sir William Herschel began, in 1785, to construct a telescope forty feet long, and in 1789, on the day when it was completed, he discovered with it the sixth satellite of Saturn. The great speculum was more than *four feet* in diameter, and weighed two thousand one hundred and eighteen pounds. Its focal length was forty feet. The tube which contained it was made of sheet iron.

The *light* afforded by this instrument was astonishingly great. The largest fixed stars, as Sirius, shone in it with the splendor of the sun. The reason of this will be obvious when we reflect that it collected and conveyed to the eye, in place of the small beam that enters the naked organ, a beam of light from the star more than four feet in diameter. Hence it was suited to reveal to the eye numberless stars and clusters of stars, which preceding telescopes had failed to exhibit, because they could not collect a sufficient quantity of their light. To economize the light to the best advantage, the small mirror employed in the Gregorian telescope (see Fig. 134.) was dispensed with, since every successive reflexion dissipates a considerable portion of the light, and the image was thrown near to the open mouth of the tube, where it was viewed by the eye-glass directly, the observer being seated so as to look into the mouth in front. In order to prevent the head from obstructing too much of the light, the image was formed near one side of the tube. Its greatest magnifying power was six thousand four hundred and fifty; but this was used only for the smallest stars.

This great telescope was mounted out of doors in a frame of proportional size; but by exposure to the weather, the frame has recently become so much decayed that it has been taken down and another telescope of twenty feet focus erected in its place.

Give an account of Herschel's great telescope. When was it made? What was the size and weight of the great speculum? To what point was the image thrown?

APPENDIX.

OF PHILOSOPHICAL APPARATUS AND EXPERIMENTS.

The utility of experiments for verifying the truths of philosophy, and for impressing them upon the memory of the learner, is universally acknowledged. Experiments, indeed, constitute the true and legitimate kind of entertainment, by which the less attractive parts of this science are to be rendered acceptable and pleasing to the young learner.

In most of our schools, however, few or no experiments are given in connexion with the study of Natural Philosophy, either from the want of suitable apparatus, or of leisure or inclination on the part of the instructor.

Although accurate and expensive instruments are highly useful for the purpose of verifying the doctrines of philosophy, still, numerous and useful illustrations of philosophical principles may be exhibited by apparatus of an inferior kind, such as can be constructed under the direction of the experimenter himself, by ordinary mechanics. An ingenious artizan, furnished with suitable cuts or drawings, with a few directions from the teacher, will construct many articles of apparatus, that will answer the purpose nearly as well as more expensive instruments. For instruments of the better sort, however, it will generally be found more advantageous to apply to professed instrument makers, a number of which will be found in each of our large cities.

The following list of articles, with such additions as every one may easily make for himself, will be sufficient for performing *the experiments* necessary to accompany the present work.

1. *Atwood's Machine*, (Fig. 2, p. 25.)—This is one of the most useful articles of apparatus, since it affords the means of verifying the fundamental principles of mechanics. See pp. 25, and 43.) It is, however, too expensive to be comprised in small collections of apparatus.

2. *Whirling Tables.*—These afford an instructive exemplification of the principles of rotary motion, and the doctrine of *centrifugal force.*

3. *Center of Gravity Apparatus.*—Several articles, of the nature of toys, are sold at the instrument maker's which afford a pleasing illustration of the doctrine of the center of gravity.

4. *Mechanical Powers.*—A set of these, in brass, connected together in the same frame, is sold in the shops. They afford pleasing illustrations of the principle of the Lever, the Wheel and Axle, &c.

The principles of HYDROSTATICS and PNEUMATICS, are susceptible of very striking and accurate verification by means of suitable apparatus.

5. *Bent Tube*, (Fig. 66.)—Or, the apparatus represented in Fig. 67, may be easily formed by inserting into a strong wooden box, made water-tight, glass tubes, or vessels of almost any shape, as a broken decanter, or glass receiver.

6. *Hydrostatic Paradox*, (Fig. 68.)—This may be made by a saddler, or better by a professed bellows-maker. Two circular pieces of hard, close-grained wood, eighteen inches in diameter and two inches thick, are used for the top and bottom. To these is nailed a piece of the strongest leather, well soaked with oil, or saturated with melted tallow. The glass tube, instead of ascending from the side, as represented in Fig. 68, may more conveniently be attached to a large screw inserted in the top board, near one side. This may be unscrewed for the purpose of introducing water. The glass tube may be about three feet long, and of quarter inch bore. Although very heavy weights may be raised by a small quantity, as half a gill, of

water, yet they rise through so small a space as hardly to be perceptible, and the experiment is not sufficiently striking to interest the spectator. The motion, however, may be multiplied by connecting a lever and multiplying wheels with the bellows, by which means a very small motion of the bellows will give a rapid revolution to a pointer, and thus render the verification of the doctrine entirely satisfactory. Such a multiplying apparatus has been connected with the bellows belonging to the apparatus of Yale College, so that half a gill of water will communicate a rapid motion to a pointer, when the bellows is loaded with a weight equivalent to or five hundred and sixty pounds.

7. *Specific Gravity Apparatus.*—A box of instruments under this name is sold in the shops; but an accurate pair of scales and weights, a hook being attached to the bottom of one of the scales is all that is sbsolutely required, beyond such apparatus as every one may command.

8. *Air Pump*, (Fig. 73.)—A double barrelled air-pump, of the kind represented in Fig. 73. with the various appendages that usually accompany it, is a most important article of philosophical apparatus. The experiments performed with it, upon the pressure and elasticity of the air, are easy to the experimenter, and novel, entertaining, and instructive to the learner. The barrels are sometimes made of glass instead of brass. which has the advantage of rendering the process of exhaustion visible to the learner. Such barrels are also preferable to those of brass, on account of their being less liable to corrode from the action of the oil employed to soften the valves and tighten the juncture of the piston.

9. *Condensing Syringe*, (Fig. 76.)—Sometimes a copper bottle furnished with several spouts for projecting water in different shaped jets, is sold with the condensing syringe. This apparatus is useful for illustrating the principles of spouting fountains, the fire engine, &c.

10. *Barometer.*—The mountain barometer, which is adapted either for indicating changes of weather, or for taking heights, is the kind to be preferred. It would be conductive to the interests of science, for every literary institution to keep an accurate daily register of the states of the barometer and thermometer.

11. *Syphon Tube.*—A common glass tube, bent over a dish of coals, will answer every purpose of a syphon.

12. *Pump Models.*—(Figs. 79. 80.)

13. *Model of the Steam Engine.*—This will be found highly instructive and interesting to pupils. They are made of various forms, but are usually somewhat expensive.

14. *Electrical Machines,* (Figs. 86. 87.)—The subject of electricity, can scarcely be understood without experiments. A considerable number of these, however, can be performed with such a humble apparatus as that described on page 223; but a well selected electrical apparatus is not very expensive, and is a great ornament to a collection. Nearly all the articles represented in the figures under the head of Electricity are required, together with several mentioned in the text.

15. *Horse-shoe Magnet.*—A large magnet of this kind will be sufficient for verifying the most important laws of magnetism.

16 *A concave and convex Mirror.*

17. *Two Prisms.*

18. *Perspective glass,* (Fig. 126.)—The lens belonging to this instrument, (the mirror being taken off,) will be found very convenient for experiments on refraction, being ready mounted on a stand.

19. *Microscope.*—One or two single microscopes of different powers, will be sufficient to illustrate the theory of the instrument.

20. *Magic Lantern.*—This apparatus with transparent figures, is not expensive, and affords a pleasing exemplification of the magnifying power of lenses.

21. *Solar Microscope.*—This is a very interesting piece of

apparatus, and should accompany every collection where the expense can be afforded.

22. *Achromatic Telescopes.*—A telescope of two inches aperture will, if well constructed, be sufficient to afford good views of the moon and of Jupiter's satellites.*

The expense of the foregoing apparatus will of course vary with its quality. The entire collection, made in the best manner, would not cost more than one thousand dollars, and when constructed in a style less finished and elegant, but still in such a way as to answer the purpose of illustration, the cost might be as low as five hundred dollars. Taking out Atwood's Machine, the model of the Steam Engine, and the Telescope, the remaining articles would not cost more than from one hundred and fifty to two hundred dollars.

*Reflecting Telescopes are made by Mr. Amasa Holcomb of Southwick Mass. which are afforded at a price much less than that of Achromatic telescopes of eqivalent power. One suited to the wants of an Accademy may be had for one hundred dollars. He makes very fine instruments for five hundred dollars.

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